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Ride Shared Vehicle Paratransit System

JULY 1977

FINAL REPORT

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16. Abstract
This research project has been concerned with developing strategies to utilize more effectively and efficiently the existing resources of the taxi industry and other paratransit service organizations. The major emphasis has been to develop the Ride Shared Vehicle Paratransit (RSVP) System, which provides hardware and software support for computer-based fare calculation and display within the existing institutional and regulatory framework of the taxi industry. The project has utilized Peoples Cab Company, an operating taxi company owned by the Center for Entrepreneurial Development, a non-profit corporation affiliated with Carnegie-Mellon University. Taxi service from the RSVP System is requested either through a telephone call or street hail. The operator enters trip data via the RSVP Operations Console and initiates a routine which calculates the fare and the estimated trip time; the results are displayed on the Operations Console and communicated to the customer prior to the trip. If either exclusive ride or shared ride service is desired, the operator specifies which vehicle will provide the service and initiates transmission of trip data to the appropriate vehicle. The concept of computer-based point-to-point fare calculation and the discount rates based on such fare calculation for various classes of group ride services have been approved by the Pennsylvania Public Utility Commission.

17. Key Words
Dial-a-Ride, Paratransit, Taxi, RSVP System, Automated Fare Calculation, Electronic Taxi Meter, Paratransit Control Systems.

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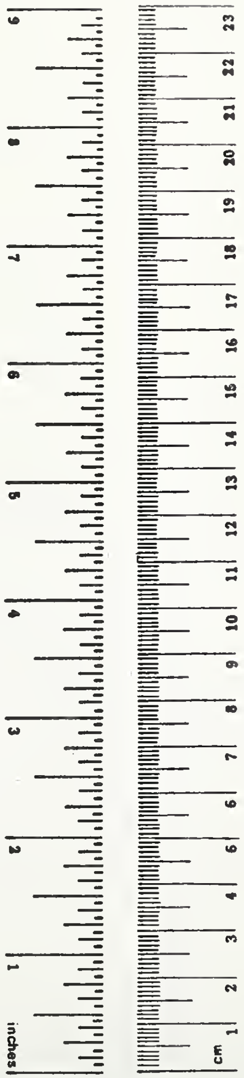
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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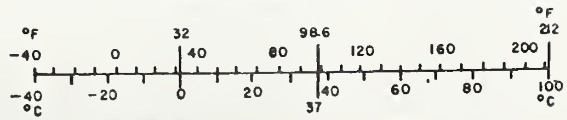
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



RIDE SHARED VEHICLE PARATRANSIT SYSTEM

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1. EXECUTIVE SUMMARY

1.1 Introduction

A variety of public transportation systems other than fixed-route, fixed schedule mass transit are becoming available in urban areas. Although many such alternative systems are in the experimental stage, potential clearly exists to improve levels of service to the public. Unfortunately, few of these innovations can be regarded as unqualified successes. Often they have not effectively utilized new technology, required substantial subsidies, and have been faced with rigid institutional and regulatory constraints.

Demand responsive dial-a-ride service is one innovation in the paratransit spectrum that is currently receiving national attention. Despite the difficulties of obtaining sufficient riders for bus-oriented systems, most demonstrations have relied upon mini-bus operations to provide faster service to line haul routes and supplementary loop or route deviation service in surrounding low density areas. Such systems have typically offered a single class of service to well defined areas, and have thus required fare structures based upon large geographic zones. In addition, the problems associated with efficient scheduling and routing of vehicles, coupled with wage packages prevalent in the transit industry, have led to little or no economies in existing dial-a-ride operations.

Given the relatively low productivity of the taxi industry (which at present provides many paratransit services) any utilization of existing but idle capacity could serve as a model for increasing the effectiveness and efficiency of other paratransit services. Past attempts to innovate in the taxi industry have been hampered by regulatory constraints and the lack of fare calculating and display systems that could satisfactorily address problems associated with shared-ride services. In part, the slow growth of the taxi industry as compared to the marked increase in total urban travel can be attributed to these factors. Similarly, the growth of other paratransit services has been hampered by the fact that such services did not exist, and typically were not even anticipated as transportation regulations evolved. Finally, institutional and regulatory constraints have also inhibited paratransit-related technological developments since a viable market for large scale production does not exist.

In response to the increasingly complex problems associated with providing reliable and comfortable urban and suburban transportation service, this research project has been concerned with developing strategies to utilize more effectively and efficiently the existing resources of the taxi industry and other paratransit service organizations. The major emphasis has been to develop the Ride Shared Vehicle Paratransit (RSVP) System, whichis designed to provide hardware and software support for computer-based fare calculations and for remote vehicle display capabilities. The project has utilized Peoples Cab Company, an operating taxi company owned by the Center for Entrepreneurial Development, a non-profit corporation affiliated with Carnegie-Mellon University. Peoples Cab Company was acquired as an experimental facility in the belief that an urban experiment station similar to the agriculture experiment station is needed for technology delivery research and demonstrations in an urban environment.

1.2 Objectives

The goal of this research project has been to design, develop, and implement an experimental demand-responsive multi-origin/destination taxi system that may be used in a variety of paratransit service organizations. Specific objectives have been to:

(1) Analyze, with particular emphasis on fare structures and operating procedures, the effects of institutional and regulatory policies on the taxi industry;

(2) Design and construct computer-based hardware and software support systems for fare calculations in shared ride paratransit transportation services; and

(3) Perform preliminary testing of the technology, pricing policies, and operating procedures of the RSVP System in an experimental operating environment.

The project was initiated in July, 1974 and completed in July, 1977, with major activities divided into three stages:

(1) Preliminary design for single origin/destination trips (exclusive ride taxi service);

(2) Prototype design for multi-origin/destination trips (shared ride taxi service); and

(3) Introduction of the RSVP System into Peoples Cab Company operations for experimental evaluation.

A separate technical report has been prepared for each of the first two stages and submitted to the U.S. Department of Transportation. This final report summarizes the results of the entire project, including the elements developed in the first two stages which were modified for experimental operations in stage three. The results have been disseminated to the paratransit industry, state and local planning and regulatory agencies, and other public and private transportation related organizations through technical reports published by the U.S. Department of Transportation.

1.3 Problem Definition

Rapidly escalating costs, in conjunction with growing consumer and regulatory agency resistance to fare increases, have forced taxi operators to seek ways to improve fleet productivities. The most straightforward method for achieving this goal is simply to increase utilization of existing fleet vehicles; however, a variety of institutional, regulatory, and technological constraints have hampered the development of shared ride systems which could improve productivity. To address these problems, RSVP System design goals were developed by considering perspectives of the public, regulatory authorities, drivers, and management.

In general, the public is concerned with obtaining safe, reliable, convenient, and comfortable transportation at a reasonable price; thus one project task was to develop pricing policies which differentiated between the shortest time path trip and a longer (due to route deviations) yet lower

priced trip for shared ride services. Similarly, a regulator's perspective requires the same standard of service (implying that regulators must be persuaded that consumers are in fact willing to trade some amount of travel time for a lower priced service). In addition, the regulator's perspective has an added dimension of enforcement, thus a second design goal was to develop a system that could be readily monitored and audited by appropriate authorities.

In any labor intensive transportation service, the acceptance of an innovation by drivers clearly affects the long-term viability of the innovation. In particular, the relationship between a company and its drivers (i.e. whether drivers are hourly employees, commission employees, lessees, or owner/operators) significantly affects which types of service offer the strongest incentive to drivers to provide such services. Finally, since invariably it is management which must undertake to implement an innovation, expected benefits must be such that a company's over-all profitability is enhanced.

In this context, development of the RSVP System required:

(1) providing justification to the Pennsylvania Public Utility Commission that the concept of shared ride transportation service was in the public interest;

(2) designing hardware and software support systems to provide an equitable fare calculation and display system for shared and exclusive ride services;

(3) developing policies and procedures for implementing the system in a limited manner for testing in taxi operations.

1.4 Research Results and Applications

Development of the RSVP System has led to numerous contacts with the Pennsylvania Public Utility Commission to define appropriate procedures for the use of the systems's computation, communication, and control techniques in actual taxi operations. The guarantee of a consistent fare for a specific trip (since fares are computed using an algorithm and a well-defined data base), and the inherent real time audit capability of the RSVP System, have provided a rational basis for examining the efficiency and equity issues of exclusive ride and shared ride taxi services.

Perhaps the most important aspect of project implementation derives from the approach used in obtaining regulatory approval for shared taxi service. Peoples Cab Company, in contrast with most other taxi companies in Pennsylvania, chose to file a tariff under its existing Certificate of Public Convenience, rather than to apply for an entirely new certificate. The PUC's acceptance of this approach gives additional strength to the argument that shared ride services (i.e., paratransit services) are and have been clearly in the province of taxi operations. In particular, the tariff approach is extremely significant in Allegheny County, Pennsylvania. Port Authority Transit, the area-wide public mass transit agency, has taken the position that it has the authority to regulate paratransit transportation services if such services are provided in vehicles other than sedan taxicabs. In addition, a number of social service agencies in the County which generally provide transportation to elderly and handicapped persons, are presently involved with applying for replacement equipment under the auspices of section 16 (b) 2 of the Urban

Mass Transportation Act. Again, there are jurisdictional questions with far-ranging ramifications that need to be resolved, and the fact that a Certificated taxi company has an approved tariff (as opposed to a temporary certificate for a new service) should be a substantial force to insure that taxi operators are not excluded from the growing paratransit market.

A second significant aspect of development has been the extension of the concept of computer-based point-to-point fare calculations to shared ride services. Several electronic meters with multiple fare capabilities are commercially available; however, these meters penalize current passengers if any route deviation occurs when additional passengers enter the vehicle. In contrast, point-to-point fare calculation based on a coordinate grid representation of the street network permits fare calculations as if each passenger had exclusive use of the vehicle. The computed fare can then be appropriately discounted to reflect shared ride service. Furthermore, acceptance of the computer-based fare calculation mechanism provides a foundation from which other technological innovations can be introduced. For example, microprocessor technology and improved digital communication techniques should have a substantial impact on information processing, monitoring, and analysis capabilities in future paratransit services.

The fare for exclusive ride taxi service is calculated on the basis of estimated travel distance and travel time. Zone-to-zone time and distance data are obtained from a Time/Distance File originally developed by the Southwestern Pennsylvania Regional Planning Commission (SPRPC) as an aid for transportation planning. The file contains shortest-time-path distances and travel times between all possible pairs of traffic zones. An Address-Coordinate File, also developed by the SPRPC, associates state plane coordinates with all street addresses in the service area. The time and distance for a trip between a specific origin and destination pair are obtained by adjusting the zone-to-zone time and distance in the Time/Distance File by a correction factor based on information available in the Address-Coordinate File. The time and distance data for a number of actual taxi trips have been collected and statistically analyzed. The fare calculation procedure is also being validated by comparing computed fares with meter fares obtained from taxi manifests.

In the case of shared ride taxi service, the fare for each passenger is based upon a discount from the fare which would be charged if normal taxicab service has been requested. If two or more passengers having the same origin and destination request Group Taxicab Service, the total fare is a discounted fare for one person, plus a surcharge for each additional person in the group. Since point-to-point distances and times for <u>direct</u> trips are used to compute normal taxicab fares, customers are not penalized for route deviations which occur in shared ride taxi service. The surcharge for each additional passenger in any group having the same origin and destination is necessary since in shared taxi service the number of vacant seats is a critical parameter (i.e., it determines whether the vehicle is still potentially shareable.) At the time of a request for service, the customer is informed of the least expensive class of service, the estimated time before a vehicle would be available, and the estimated travel time for exclusive taxicab service.

The RSVP System Control Center is the focal point for all operations. Basic hardware components are the Central Computer System, a microprocessor-based Interface Console with an auxiliary keyboard for vehicle communications, and additional communication equipment for transmitting and receiving vehicle messages. Basic software components consist of vendor-supplied language processors, utility programs, and an operating system, in addition to the RSVP System Data Base Management System.

The Data Base Management System provides a control structure which links processing modules and data files in the RSVP System. It includes:

(a) A file structure for travel times and distances between zones in the service area;

(b) A file structure for state plane coordinates of all street addresses in the service area;

(c) Subroutines for obtaining and validating trip data, computing and displaying fare information, and interpreting and executing commands.

The Central Computer System consists of a DEC PDP-11/10 minicomputer with 16K words of core memory, a real-time clock, and an Extended Arithmetic Element to permit fixed point integer multiplication and division operations. System peripherals include a cartridge disk system with a capacity of five million words, a teletype terminal which serves as the Master Console and a hardcopy device, and a CRT terminal which serves as an Operations Console. Due to the limited main memory capacity and the necessity for fast program execution, most RSVP System software is coded in PDP-11 assembly language, although the main control program is coded in FORTRAN. The Data Base Management System is initiated via the vendor-supplied operating system (RT-11); however, after initiation, the Data Base Management System functions in a stand-alone mode and controls all computer resources. Other vendor-supplied programs such as the text editor, the FORTRAN complier, the Assembler, and a file maintenance program are also required to support continuous RSVP System software development. A telephone communication link to Carnegie-Mellon University utilizes standard asynchronous line interfaces and modems. It currently permits communication with remote computers at 1200 baud (120 characters per second) and programs have been developed for using other computer systems as back-up systems.

The RSVP System vehicle hardware package consists of a commercially available VHF FM radio transceiver and a custom-built RSVP meter. The radio transceiver and the RSVP meter are connected by a cable. The RSVP meter contains three major components which are packaged in a compact aluminum enclosure with a locking mechanism:

(a) A communication interface which includes all circuits for the radio-meter interface.

(b) A numeric display which allows 4 digits of fare information, 2 digits of estimated trip time, and 1 digit for seat or passenger identification;

(c) Metering circuitry which provides back-up fare calculation capabilities in the event of a computer failure.

The frequencies used for vehicle communications conform to U.S. standards for low speed FSK modulation, and the RSVP System operates on an exclusive radio channel. The communication interface of the RSVP meter performs parity error checking and sends a positive acknowledgment to the Interface Console, indicating whether or not transmissions have been received correctly. Microprocessor technology has been incorporated into the RSVP System via the Interface Console which serves as a communications front-end for the PDP-11 by buffering information to be transmitted to vehicles, initiating actual transmissions, and determining whether any parity errors occurred. An auxiliary keyboard will permit transmissions to vehicles independent from the Central Computer System; thus communications can occur even if the Central Computer System has malfunctioned. The numeric display shows the trip fare and estimated trip time generated by the Central Computer, or the fare determined by the electronic meter in the event of a computer failure. The metering circuitry for back-up fare calculation essentially simulates the conventional taxi meter. A Hall-effect sensor mounted on the transmission generates pulses proportional to distance travelled, and an internal oscillator generates timing pulses both for metering and for communication synchronization.

Taxi service from the RSVP System is requested either through a telephone call from a customer or by a radio message from a driver who has been hailed on the street. The Operator enters trip data via the Operations Console and initiates a routine which calculates the fare and estimated trip time. The results are displayed on the Operations Console and communicated to the customer; if service is desired, the Operator specifies which vehicle will provide the service and initiates transmission of trip data to the appropriate vehicle. The Interface Console stores trip data in a buffer, transmits data to the vehicle, and verifies that data has been received. The RSVP Control Center is located in Peoples Cab Company, and four RSVP meters are operating in the company's fleet.

1.5 Conclusions and Recommendations

The RSVP System represents a significant advance in understanding and implementing demand-responsive systems for paratransit services. Use of the System in limited operations has demonstrated the technical and regulatory feasibility and viability of the concept of computer-based shared ride fare calculations. Clearly the next step should be additional testing of the system, first with an emphasis on marketing and public acceptance of the fare in advance concept; then with a variety of fare policy experiments to gain some operating and economic data concerning consumer preferences for lower priced but less direct door to door transportation services. Subsequent to these activities, a large scale demonstration of the concept, incorporating centralized scheduling and routing in an entire region, should be undertaken. Such a demonstration of the RSVP System for all types of paratransit services should provide the necessary incentive to stimulate the interest of the taxi industry to play an important role in providing paratransit services in the future. In turn, a committment from the taxi industry should substantially aid in solving the myriad problems of urban and suburban transportation.

2. INTRODUCTION

2.1 Paratransit Transportation Options

The trend towards suburbanization in regions surrounding major cities in the United States has been apparent for three decades; thus downtown oriented fixed route transit is becoming increasingly less relevant to urban living if no supporting systems are provided. Despite the generally recognized potential of flexible route systems to meet this need, a critical missing element in the public transportation systems of practically all major cities has been the lack of viable integrated transportation services for low population density suburbs.

In this context, while the taxi industry represents a sizable portion of the transportation sector, paratransit constitutes a second major (and growing) portion. In general, paratransit can be defined as any shared ride transportation service that falls between exclusive ride taxi service and line haul (fixed-route, fixed-schedule) bus service.[1] Important paratransit attributes are door-to-door service, demand responsive (to the customer's time constraints) scheduling, and shared use of vehicles (multiple origin-destination pairs occupying the vehicle at a given time).

Given this broad array of transportation options, taxi operators, perhaps more than any other group of private or public agents, can play a significant role in providing paratransit services. Although bus operators have expressed interest in paratransit, little has been offered in the way of service since inter- and intra-urban bus companies provide services very different from paratransit. Bus operators cannot evolve into paratransit service using existing fleets and procedures, whereas the taxi industry, since it currently provides door-to-door randomly scheduled transportation, is clearly capable of expanding to include shared ride paratransit services.

The fact that the taxi industry has not fully realized its potential in the paratransit sector can be attributed to a number of software and hardware limitations, as well as to attitudes within the taxi industry of skepticism towards technological innovation. Software constraints include those imposed by regulatory and political processes in addition to those related to specific managerial and operational problems. Hardware constraints have continued to exist since there are no strong incentives for technological innovation or product improvement. Even with a reasonable market for paratransit-related technological innovations, implementation would still be hindered by the fact that hardware developments are inextricably bound to a variety of regulations covering paratransit services. Clearly, the public as well as governmental agencies must be persuaded that innovative paratransit transportation services will also entail changes in regulatory and political processes.

2.2 Taxi Industry Potential

The taxi industry most probably evolved in a bygone era when people owning cars and carrying friends and neighbors subsequently began charging a fee to help defray costs. Although many of these so-called jitney operations

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1 Kirby, R. F. et.al., Paratransit: Neglected Option for Urban Mobility, The Urban Institute, Washington, D. C., 1974.

have since been legislated or regulated out of existence, the International Taxicab Association (ITA) recently estimated that there are 5,000 fully licensed fleets operating in 3,000 localities with approximately 200,000 vehicles in the United States. Taxi companies operate almost three times as many vehicles as the mass transit industry, and the ITA estimates that the taxi industry realized gross passenger revenue of approximately $5 billion in 1975.

The majority of fully licensed cabs are fleet taxis (i.e. controlled by an organization which operates more than one vehicle). Typically the organization will provide centralized telephone answering, dispatching, maintenance, and repair facilities. In many areas the regulatory environment is such that only franchised fleets are permitted to operate. There are sizable economies of scale which can be realized in fleet operations, particularly in the areas of insurance, financing, maintenance, and dispatching.

Traditionally, taxi hardware components have consisted of the four-door sedan, the two-way radio, and the taxi meter. The meter computes a fare based upon an established rate per mile and per minute by simply accumulating the greater of the time rate or the distance rate, plus a fixed amount for the so-called flag drop (a surcharge for initial vehicle availability). In some areas, charges for extra luggage, trips to special places such as an airport, or extra passengers may be added to the meter fare.

The impact of introducing the meter closely parallels the evolution of the cash register in modern retailing. The basic cash register began as simply a drawer with an audible signal, thus an owner could leave the immediate area of the cash box and still know when it was being opened. Eventually the technology for cash registers (i.e. the hardware and software support systems) allowed the customer to help maintain the integrity of the system, first with numeric indicators and later with printed receipts. Perhaps the stipulation that returns or refunds are not made without a receipt has as great an impact on keeping the original transaction honest as it does on permitting reasonable adjustments to be made after purchases to insure customer satisfaction. In other words, a system of managerial and customer monitoring of retail transactions evolved as the relationships among human and organizational systems increasingly exploited technological innovations which became available.

Various hardware systems such as seat occupancy sensors have been used in attempts to guarantee activation of the meter; yet the effectiveness of these methods has been limited by the ease with which they may be subverted. An electro-mechanical meter records data for exclusive ride fares (one origin-destination pair in a vehicle at a given time); however, it cannot record data for shared ride fares (multiple origin-destination pairs in a vehicle at a given time). Recent announcements by several manufacturers of taxi meters indicate a trend toward meters with shared ride capabilities; yet these meters penalize a customer already in the vehicle if route deviations are required to pick up additional customers. One of the greatest deterrents to public confidence in the taxi industry relates to trips which take longer than the shortest distance between the origin and destination points. Since the shortest time path, the shortest distance path, and the least cost path are not necessarily the same, there is always a potential for drivers to short change customers and/or management.

The zone fare concept is a system which attempts to alleviate customer fears of overcharging based upon circuitous routing using a meter. Unfortunately, for short trips within a zone the customer feels cheated; yet for long trips within a zone the driver and/or management feels cheated. With rare exceptions (Washington D.C. being a notable one), zone fares exist primarily in small cities and rural areas because the zone boundaries in large cities are not easily recognizable to the public. Thus, it seems reasonable to assume that the almost guaranteed inequities inherent in zone systems have been perceived by customers as out-weighing the possible benefits of not being overcharged by a circuitous metered trip. The taxicab industry has been hampered in its growth into various classes of paratransit service by the fact that it has not had the equivalent of the cash register to provide an accurate, auditable record of all possible payment transactions for service.

Taxi drivers are typically compensated through some form of output-related incentive scheme, usually a commission of 30% to 50% of their gross receipts. A smaller number of persons own their vehicles, retain all gross receipts, and are solely responsible for all expenses. In some instances these owner/operators form associations and essentially operate as fleets. In addition, a third class of driver, the independent contractor, is gaining increased popularity throughout the taxi industry. Under this arrangement, an individual rents or leases a vehicle (sometimes including a meter and radio) from the company for either a fixed daily or hourly fee, or for a fixed fee plus a mileage charge, and in turn retains all receipts. The important factor is that lease drivers are not considered employees; hence the company can avoid employee-related expenses such as tax withholding, workmen's compensation, and other administrative costs.

2.3 Research and Development

Dial-a-Ride is one paratransit innovation that is currently receiving national attention. All forms of Dial-a-Ride have the common characteristic that vehicles are scheduled and routed dynamically, thereby providing efficient, flexible service in low density areas. Vehicles can be mini-buses, vans, taxicabs, or ordinary cars. The system may be accessed either by street hail or by telephone request. Trips may range from single origin/destination individual rides to multi-origin destination shared rides. The basic goal is to provide demand responsive transportation services by implementing the combination of modes most appropriate to a specific local environment.

Although a variety of paratransit systems have attempted to promote and provide dial-a-ride services, few can be regarded as unqualified successes. They have often required substantial subsidies, have not developed the appropriate technology, and have not adequately resolved institutional and regulatory problems. A taxi approach to dial-a-ride, however, addresses these issues simultaneously in a realistic institutional and regulatory setting. For example, the Haddonfield experimental design required measuring the impact of dial-a-bus on the taxi industry, and resulted in a mechanism for assessing damages to the private sector, although most probably the full impact of this process has not been realized.[2]

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[2] Gwynn, D. W., et.al., "Dial-A-Ride Demonstrations in Haddonfield," in Demand-Responsive Transportation Systems, National Academy of Engineering, Washington, D. C., Special Report 136, 1973.

In 1971 a group at Carnegie-Mellon University decided that a Pittsburgh taxi franchise which had become available would be a useful experimental facility for studying urban transportation problems. A fundamental premise was that hands-on experience would facilitate better understanding of the taxi industry. Furthermore, it became apparent that such a system could model a variety of public transportation options without incurring large capital expenditures. In order to provide the necessary organizational framework, Peoples Cab Company was acquired by the Center for Entrepreneurial Development, a non-profit corporation affiliated with Carnegie-Mellon University. From three vehicles initially, the fleet has grown to twenty, using operating revenues. In part, ongoing experiments are designed to explore the taxi industry's potential for continued growth as a viable business enterprise providing a much needed transportation service.

The current Carnegie-Mellon paratransit research and development program primarily involves the development and implementation of an experimental demand responsive multi-origin/destination paratransit system. The design and development of hardware and software to compute and display, in advance, fares and estimated trip times for exclusive and shared ride taxi services have been accomplished within an institutional and regulatory environment similar to that found in many urban areas. The hardware and software packages are collectively termed the Ride Shared Vehicle Paratransit (RSVP) System, and are designed to be compatible with virtually all paratransit systems.

Although no proposed levels of service are entirely new, using a combination of modes to provide multipassenger taxi service raises important questions concerning market development, market aggregation, and potential economies of scale. If these issues can be satisfactorily resolved, the capability to shift dynamically from conventional taxi service to multipassenger service would significantly improve operating efficiency. Since taxicabs represent an important paratransit mode, any improvement in taxi service and efficiency would produce substantial direct and indirect benefits for the entire paratransit industry. In particular, a pricing mechanism that would maximize fleet utilization would also reduce congestion and operating costs while allowing the customer to choose a level of service between taxicabs and buses.

The fare structure of a shared ride taxi service is perhaps the most critical factor influencing its success or failure in a competitive market. Unless adequate profit incentives exist for taxi operators, service levels will deteriorate to the extent that even lower fares for shared ride service will not attract sufficient riders. In essence, fare policies should reflect that both operators and individual passengers will share the savings resulting from the improved efficiencies of shared ride services, since each party assumes some degree of risk. Paratransit services must be implemented and regulated in such a way that users are charged substantially lower fares per mile and yet operators are able to make an adequate profit due to increased total revenues without corresponding increases in total costs.

The basic approach of the RSVP System is to compute shared taxi fares by discounting the fare which individual passengers would be charged if they had taken exclusive taxi trips. Essentially, this approach requires a route

and driver independent procedure; thus a coordinate grid representation of the service area street network is used in fare calculations. With this procedure, a passenger's fare can be displayed prior to the trip; however, if the computer or radio malfunctions, the meter circuitry in the vehicle provides a back-up fare calculation capability.

Although there are other ways for structuring fares for shared ride services, the effect of inappropriate policies may produce an unstable market for taxi related paratransit services. Fares too far above or below market equilibrium could lead to damaging spirals in demand or supply. The lack of experience with widespread taxi related paratransit services makes it virtually impossible to predict with sufficient accuracy the average load factors necessary to determine fare policies. In order to gain this needed experience, and to provide an opportunity to determine equilibrium fares through trial and error without damaging the long run success of shared ride taxi services, the initial implementation of experimental operations has been on a limited basis.

2.4 RSVP System Master Diagram

The RSVP System consists of both hardware and software support systems as shown in Figure 2.1. The Control Center is based upon a Digital Equipment Corporation PDP 11/10 with 16K words (16 bits/word) of core memory, a disk cartridge auxiliary storage system, a hard-copy Master Console, a CRT Operations Console, and a microprocessor-based Interface Console. The RSVP System software includes a vendor supplied package in addition to the RSVP Data Base Management System (which consists of a FORTRAN control program capable of initiating a number of MACRO Assembly Language subroutines, depending upon the function requested by an Operations Console). Console input is interrupt driven, and up to four Operations Consoles can be utilized in the current hardware configuration. RSVP System Vehicle Hardware consists of a commercially available FM radio transceiver and a custom-built RSVP meter. A Hall-effect sensor unit is attached to a vehicle's transmission and serves as an input to the metering circuitry. The hardware has been designed to permit straightforward incorporation in a variety of paratransit vehicles.

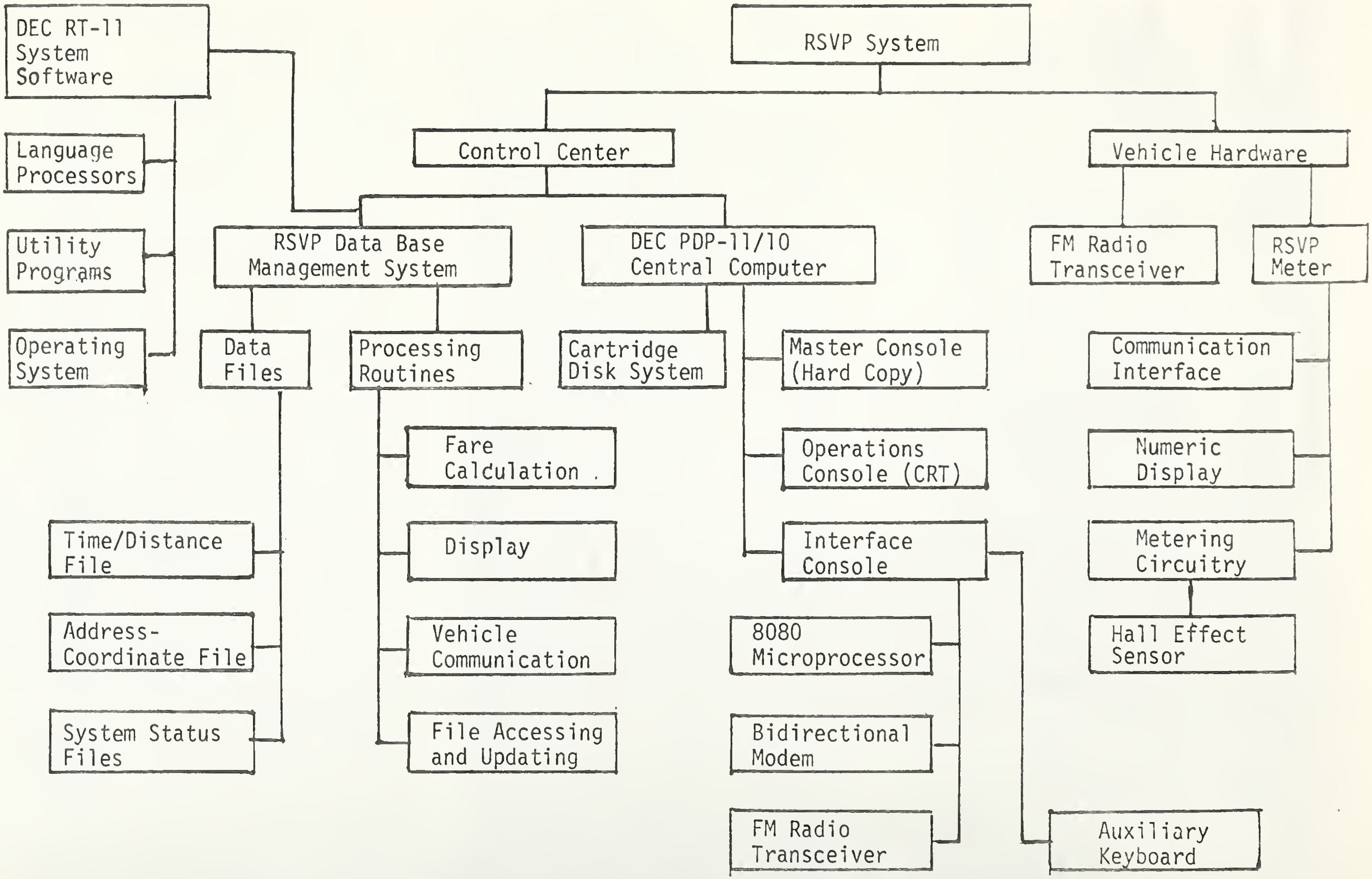


Figure 2.1

RSVP SYSTEM MASTER DIAGRAM

3. PARATRANSIT REGULATION

3.1 Overview

Although transportation regulation has evolved in different ways in different areas, paratransit services are regulated in virtually every city in the United States. In most instances, city or county governments enact and enforce regulations, although several states rely on state-wide regulation. Essentially, regulation can be viewed as a force which replaces the so-called invisible hand of competition. The basic rationale is simply to insure that service is continuously available at a fair and reasonable price, while also insuring that operators obtain an adequate return on their investment.

Typically, the following are considered when regulations are promulgated:

(1) entry controls (e.g. specification of the number of fleets and/or vehicles; specification of service territories; specification of the types of service which may be offered);

(2) financial controls (e.g. specification of minimum levels of financial resources; limitations on profits);

(3) service standards (e.g. availability and continuity of service; driver qualifications; vehicle attributes; response time, travel time, and dispatching standards; management/driver relationships);

(4) fare standards (e.g. specification of permissible rates; specification of fare calculation mechanisms; specification of conditions under which rates may be changed).

Regulation has also had a significant impact on innovation within the paratransit industry. In general, innovation either responds to a problem or a potential; however, in a regulated industry either response is tempered by the fact that rewards are limited. As a consequence, the risk associated with an innovation must be relatively low before sufficient incentive exists to actually implement it. In particular, since very little data exist upon which to base demand predictions, there has been little incentive for taxi operators to experiment with shared ride services at discount prices.

3.2 Service Regulation

The impact of regulation on paratransit service is perhaps most apparent in terms of simply obtaining legal authority to offer shared ride service. Historically, pressure from bus and trolley companies caused many regulatory agencies to prohibit taxi companies from providing shared ride service. Although these restrictions were aimed at limiting competition on lucrative urban corridors, eventually taxi operators became supportive of them also. As long as operating cost increases could be readily passed on to customers, there clearly was no incentive to dilute revenues by offering shared ride service.

Similarly, vehicle restrictions have become more important in the past ten years as van-type vehicles with seating capacities of 9 to 15 passengers have become available. Again, the threat of increased competition from taxi

companies has caused many bus transit companies to strongly oppose the use of such vehicles by taxi companies. A major dilemma now facing regulatory authorities is to define new paratransit services in such a way that existing carriers (either bus or taxi) are not automatically precluded from offering the services.

Response time (i.e. the time between a customer's request for service and the arrival of a vehicle) and travel time (i.e. the duration of a customer's trip) are important service characteristics; however, these characteristics are typically regulated only in the sense that certificated (authorized) carriers must provide continuous service. In general a new company wishing to obtain operating authority must prove that existing companies are not providing adequate service. Proof of inadequate service is then usually submitted in terms of a poor response time or travel time record, coupled with data purporting to show that specific areas are not being served.

The relationship between a company and its drivers is strongly influenced, and sometimes dictated, by regulations. The basic issue is primarily one of control. In order to insure that service is continuous, regulatory authorities have sought to control drivers through management. This philosophy has become manifested in some areas by prohibitions against taxi drivers operating as independent contractors, even though in general it is to management's advantage, due to lower tax and administrative costs to have independent contractors provide exclusive taxi service. At the same time, depending upon the actual demand for shared ride services, it may be more profitable for a company to have only hourly-paid employees operating shared ride vehicles. To realize the benefits permitted by the IRS when drivers operate as independent contractors, management must exercise relatively little control over drivers; yet to efficiently organize schedules and routes for shared ride services, there must be centralized management control. Clearly, there are difficult tradeoffs to be made among various factors such as limiting the number of vehicles in a given mode, providing a full shift of employment, and supplying a service which is characterized by heavy peaking in demand.

3.3 Fare Regulation

Any Paratransit fare calculation system must be concerned with the basic issues of equity and efficiency for customers, drivers, and management. Obviously, the fare charged should accurately reflect the costs of providing a given level of transportation service. However, an important trade-off exists between continuously charging fares to reflect current operating conditions, and providing customers with assurances that fares will be reasonably consistent from hour to hour and day to day. Any cost analysis requires support systems capable of monitoring operations and providing management and regulatory personnel with information upon which to base pricing policy decisions.

In general, fares include a fixed portion which should represent dispatching and other trip-independent operating costs, and a variable portion which is specifically dependent upon the actual distance and time required to complete the trip. Most major metropolitan areas require taxi operators to file tariffs based upon the taxi meter as a fare calculation mechanism (although Washington D.C. and Tulsa, Oklahoma are notable exceptions which permit zone fare systems).

A taxicab tariff typically specifies the amount of the initial flag drop, the distance and time included in the initial flag drop, the incremental distance charge, and, if appropriate, the amount of any surcharge (e.g. for extra passengers, extra luggage, or for trips to a particular location such as an airport). Let

F_0 = the initial flag drop (including the first δ_0 miles and τ_0 minutes)

C = the incremental distance charge (per δ miles) or incremental time charge (per τ minutes) if they are equal.

C_1 = the incremental time charge (per τ_1 minutes) if it is not equal to the incremental distance charge

j = a conversion factor such that $C = jC_1$ and $\tau = j\tau_1$

S = the surcharge for additional passengers

C_0 = the first mile cost.

Table 3.1 illustrates different fare policies for several major metropolitan areas. Although the specific amounts are out-dated, they do indicate the effects of various pricing policies with regard to the cost of the first mile of travel. This first mile charge has traditionally been viewed as a meaningful method of communicating the effects of rate changes to the public; however, it should be noted that the figure is misleading, partly because it is completely insensitive to time charges and is dependent upon the relationship between δ_0 and δ, and partly because the fare quoted for the first mile is sometimes not for a distance of exactly one mile.

For example, in nine out of fourteen cities, $\delta_0 = \delta$, but in the other cities $\delta_0 = \delta/2$. Also, in nine cities, $C_1 = C$ and $\tau_1 = \tau$, while in the remaining cities $C = jC_1$ and $\tau = j\tau_1$ with j varying from 5/6 to 2. In all cities, τ_0 is not stated explicitly and is assumed to be identical to τ. In only two cities a surcharge for additional passengers is allowed for exclusive ride service.

In terms of equity and efficiency, there is no reason to have $\delta_0 \neq \delta$ and $\tau_0 \neq \tau$. In fact, adoption of such a tariff does not even reflect the mechanism of a traditional taxi meter. As indicated earlier, $\tau_0 = \tau$ is usually assumed; however, a fare structure in which $\delta_0 \neq \delta$ in no way serves the public interest. In particular, the exact cost for the first mile of service is given by the formula

$$C_0 = F_0 + (1/\delta - \delta_0/\delta)C \tag{3.1}$$

Table 3.1

TAXI FARES IN MAJOR U.S. CITIES

(Source: November 11, 1974 New York Times)

City	First Flag Drop		Each Additional Distance		Each Waiting Period		Cost per first mile
	F_o Cents	δ_o Mile	C Cents	δ Mile	C_1 Cents	τ_1 Min.	C_o dollars
San Francisco[a]	80	1/8	20	1/4	10	0.75	1.50
Philadelphia	90	1/6	10	1/6	10	1.5	1.40
Cleveland	80	1/6	20	1/3	10	1.0	1.30
Seattle[b]	80	1/6	10	1/6	10	0.83	1.30
Los Angeles	80	1/3	20	1/3	20	1.67	1.20
Miami	60	1/7	20	2/7	10	0.75	1.20
St. Louis[b]	85	1/5	10	1/5	10	1.5	1.20
New York	65	1/6	10	1/6	10	1.5	1.15
Cincinnati	65	1/6	20	1/3	10	1.0	1.15
Houston	75	1/5	10	1/5	10	1.0	1.15
Boston	50	1/7	10	1/7	12	1.0	1.10
Detroit	60	1/6	10	1/6	10	1.0	1.10
Chicago[b]	50	1/10	10	1/5	10	0.75	0.95
New Orleans	50	1/5	10	1/5	10	1.0	0.90

[a]Additional charge for more than one passenger is 25¢ each.

[b]Additional charge for more than one passenger is 20¢ each.

Using the data for Philadelphia in Table 3.1,

$$C_0 = 90 + (6 - 1)(10) = 140 \text{ cents.} \tag{3.1}$$

In this case, $1/\delta = 6$ and $\delta_0/\delta = 1$ are both integers, thus their difference is also an integer. If the coefficient of C is not an integer, the usual practice has been to truncate the coefficient to the nearest integer. For example, if $F_0 = 90$, $\delta_0 = 1/4$, $C = 20$, and $\delta = 1/5$, then a flag drop plus 3 meter increments represents $1/4 + (3)(1/5) = 0.85$ miles; while a flag drop plus 4 meter increments represents $1/4 + (4)(1/5) = 1.05$ miles. Traditionally, then, the stipulated cost for the first mile would be $90 + (3)(20) = 150$ instead of $90 + (4)(20) = 170$ because one mile has been interpreted as the accumulated distance not exceeding one mile. This argument is the basis of the truncation of the coefficient of C to the nearest integer. Note, however, that truncation instead of rounding-off to the nearest integer is a subterfuge which does not fully inform the public. Use of Eq. (3.1) without modification will reflect more accurately the cost of the first mile on the basis of distance travelled; however, the insensitivity to time remains. Clearly, some means must be developed to analyze the efficiency and equity of a proposed fare structure in terms of distance, time, and affected parties.

3.4 System Performance Measures

In order to assess the long term viability of shared ride paratransit services, a consistent set of performance measures must be defined and adequate data collection and analysis procedures must be established. In general, these measures should monitor operations from the perspective of customers, regulatory authorities, and management, and should indicate both the quantity and the quality of services provided.

From a customer's perspective, quantity and quality can be primarily measured in terms of wait time and travel time. (Obviously, other factors such as appearance of the vehicle and comfort of the ride are related to quality; however, such characteristics are difficult to quantify in any non-subjective manner). Higher quality service is generally indicated by shorter wait times and travel times. In shared ride service, these factors vary dynamically, depending upon the number of different origins and destinations on a given tour or tour segment.

From a regulator's perspective, travel time and wait time are important measures of the level of service provided by a company; however, to enable assessment of fees and taxes, regulators also require information regarding gross receipts. In turn, this implies a requirement for detailed knowledge of the characteristics of trips (e.g. revenue miles, number of trips, surcharge revenue collected, etc.). Obviously such information is dependent upon the particular fare calculation mechanism utilized; furthermore it is necessary for regulatory agencies to verify that the particular procedure filed in a company's tariff is in fact being followed.

Finally, from management's perspective, measures of performance must incorporate cost of service information in addition to revenue and time information. Again, knowledge of the fare calculation procedure is necessary to determine accurate revenue information; at the same time, the fare calculation mechanism can also serve as a basis for making dispatching decisions. If the mechanism permits fare calculations without actually taking the trip, the least cost solution for servicing a request can be readily determined and used as a dispatching aid.

4. FARE CALCULATION PROCEDURE

4.1 Overview

Paratransit service fares may include a fixed portion independent of distance or time and a variable portion dependent on distance and/or time. In the case of metered taxi fares, the charge for the "flag drop" when boarding a taxicab corresponds to the fixed portion while the charge accumulated from meter incrementing during a trip constitutes the variable portion.

It is important that the pricing structure underlying fare calculation conform with the public interest in terms of equity and efficiency. Consequently, fare equations that simulate electro-mechanical taxi meters have been developed to provide an analytical framework for assessing the effects of various values of the fixed fare "flag drop" and the increment fare in each "tripping" of the meter and their associated distance increments and time increments. These taxi fare equations also provide a rational basis for fare calculation in advance of a trip if the distance and time for the trip can be estimated reliably.

The RSVP System for exclusive ride taxi service is calculated on the basis of estimated travel distance and travel time. Zone-to-zone time and distance and data are obtained from a Time/Distance File originally developed by the Southwestern Pennsylvania Regional Planning Commission (SPRPC) as an aid for transportation planning. The file contains shortest-time-path distances travel times between all possible pairs of traffic zones. An Address-Coordinate File, also developed by the SPRPC, associates state plane coordinates with all street addresses in the service area. The time and distance for a trip between a specific origin and destination pair are obtained by adjusting the zone-to-zone time and distance in the Time/Distance File by a correction factor based on information available in the Address-Coordinate File. The time and distance data for a number of actual taxi trips have been collected and statistically analyzed. The fare calculation procedure is also being validated by comparing computed fares with meter fares obtained from taxi manifest.

In the case of RSVP System shared ride taxi service, the fare for each passenger is based upon a discount from the fare which would be charged if normal taxicab service has been requested. If two or more passengers having the same origin and destination request Group Taxicab Service, the total fare is a discounted fare for one person, plus a surcharge for each additional person in the group. Since point-to-point distances and times for direct trips are used to compute normal taxicab fares, customers are not penalized for route deviations which occur in shared ride taxi service. The surcharge for each additional passenger in any group having the same origin and destination is necessary since in shared taxi service the number of vacant seats is a critical parameter (i.e., it determines whether the vehicle is still potentially shareable.) At the time of a request for service, the customer is informed of the least expensive class of service, the estimated time before a vehicle would be available, and the estimated travel time for exclusive taxicab service.

4.2 Fare Equations Simulating Taxi Meters

Let F_o be the fixed portion of the fare which is the initial cover charge for the flag drop when a rider boards a taxicab. This portion of the fare also pays for a ride of either a distance, δ_o, or a time, τ_o, whichever is reached first. Let F_c = CN be the variable portion of the fare, in which N is the number of times the meter trips during a ride; and C is the incremental fare for every additional distance increment δ or time increment τ, whichever is reached first. Thus, the total fare for a ride is given by

$$F = F_o + F_c = F_o + CN \tag{4.1}$$

The mathematical formulation of the problem can be slightly simplified without losing the generality by first considering the case of $\delta_o = \delta$ and $\tau_o = \tau$. Let x(t) be the odometer reading of a vehicle at time t and let t(x) be the time for the vehicle at odometer reading x. Since x(t) is a monotonically increasing function of time, its inverse function t(x) exists and is a monotonically increasing function of distance. The trajectory of the vehicle with respect to distance and time is shown in Fig. 4.1. Thus, for $\delta_o \doteq \delta$ and $\tau_o = \tau$, the flag drop of the meter has the same incremental effect on distance or time as the subsequent trippings. Let x_n be the position of a vehicle when the meter trips the nth time, and let t_n be the time when the meter trips the nth time. Then, the nth travel segment is that portion of travel which takes place between x_n and x_{n-1} and occurs between t_n and t_{n-1}. That is

$$\Delta x_n = x_n - x_{n-1} \tag{4.2a}$$

$$\Delta t_n = t_n - t_{n-1} \tag{4.2b}$$

in which $x_n = x(t_n)$ and $t_n = t(x_n)$.

Let X be the total distance traveled and T be the total time lapsed at the end of a ride. Then, the equations for fare calculation can be based on a pair of coupled recurrence equations for n = 1,2, ...,N:

$$x_n = x_{n-1} + \min\left\{ \delta, [x(t_{n-1} + \tau) - x_{n-1}] \right\} \tag{4.3a}$$

$$t_n = t_{n-1} + \min\left\{ [t(x_{n-1} + \delta) - t_{n-1}], \tau \right\} \tag{4.3b}$$

Noting that $x_o = 0$ and $t_o = 0$, the equations can be solved for x_1, x_2, ..., x_N and t_1, t_2, ..., t_N, in which N is the last time the meter trips. Note also that

$$x_N \leq X < x_{N+1} \tag{4.4a}$$

$$t_N \leq T < t_{N+1} \tag{4.4b}$$

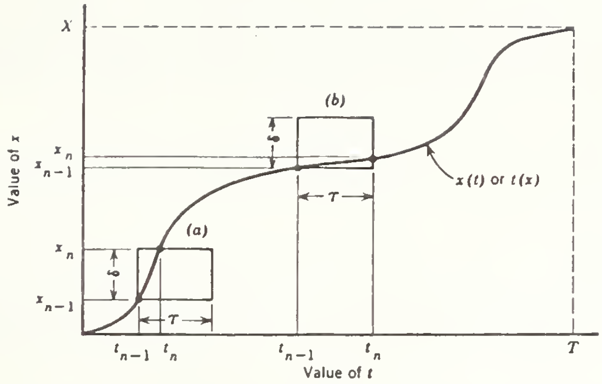


Figure 4.1

GEOMETRICAL INTERPRETATION OF METER TRIPPING WITH RESPECT TO DISTANCE AND TIME: (a) FAST MOVEMENT; (b) SLOW MOVEMENT OF VEHICLE WITH RESPECT TO LOCATION AND TIME

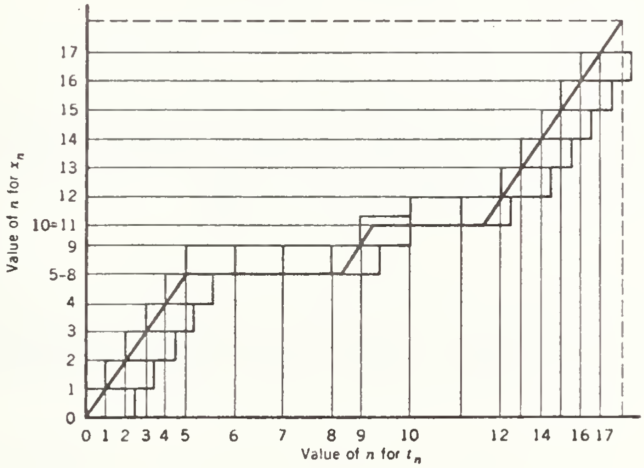


Figure 4.2

IDEALIZATION OF TRAJECTORY IN STOP-AND-GO TRAFFIC

Thus, x_N and t_N are the nearest truncated values or measurable approximations for X and T, respectively, since N is restricted to be a positive integer and (N + 1) refers to the travel segment after the rider has departed.

If $\delta_0 \neq \delta$ and $\tau_0 \neq \tau$, Eqs. (4.3a) and (4.3b) are still valid for n = 2,3, ..., N. However, for n = 1, the following conditions prevail:

$$x_1 = \min [\delta_0, x(\tau_0)] \tag{4.5a}$$

$$t_1 = \min [t(\delta_0), \tau_0] \tag{4.5b}$$

This modification will not materially affect the solution of these equations.

The fare equations based on the trajectory of vehicle position and time can be interpreted geometrically by considering two cases of special interest as shown in Fig. 4.1. The instantaneous velocity, v, of the vehicle at any point is given by the slope of the trajectory, dx/dt, at that point. The two cases of interest are: (1) the fast movement of the vehicle when $v > \delta/\tau$; and (2) the slow movement of the vehicle when $v < \delta/\tau$. In each case, a rectangle of dimensions, δ and τ, is drawn with (x_{n-1}, t_{n-1}) at the lowest left corner. For fast movements, the meter trips for every distance increment, δ, and the point (x_n, t_n) is determined by the travel distance. For slow movements, the meter trips for every time increment, τ, and the point (x_n, t_n) is determined by the time lapsed. Thus, during a ride of total distance X and total time T, it can be expected that the meter reading is determined by a combination of distance segments and time segments.

Note that if the variable fare, F_c, can be expressed as a linear combination of x_N and t_N, then it can also be expressed as the sum over all travel segments of the same linear combination of distance segments Δx_n and time segments Δt_n. Let A and B be positive constants such that

$$F_c = Ax_N + Bt_N \tag{4.6}$$

Since $x_N \approx X$ and $t_N \approx T$ as indicated in Eqs.(4.4a) and (4.4b), it follows from Eq. (4.6) that

$$F_c \approx AX + BT \tag{4.7}$$

The vehicular traffic in cities is characterized by periods of stop and go. Thus the metered taxi fare in congested traffic conditions is generally based on some combination of distance segments and time segments. If the stop-and-go traffic is idealized by the approximation that the vehicle is either moving with a constant speed, $V > \delta/\tau$, or is stationary, then the trajectory of the vehicle can be represented by straight line segments, an example of which is shown in Fig. 4.2.

Let r be the number of times that the meter trips on the basis distance increment δ, and let s be the number of times that the meter trips

on the basis of time increment τ during a ride, such that $r + s = N$. Let X_r be the total distance traveled at speed V, and let T_s be the total time lapsed at the stops ($v = 0$). If $\bar{X}_r/\delta$ denotes the largest integer that is less than or equal to X_r/δ, and $\bar{T}_s/\tau$ denotes the largest integer that is less than or equal to T_s/τ, then

$$r = \frac{\bar{X}_r}{\delta} \text{ and } s = \frac{\bar{T}_s}{\tau} \tag{4.8}$$

Since no distance is traveled during the total time lapsed at stops

$$X_r = X = V(T - T_s) \tag{4.9a}$$

or

$$T_s = T - \frac{X}{V} \tag{4.9b}$$

Thus

$$N = \frac{\bar{X}_r}{\delta} + \frac{\bar{T}_s}{\tau} \approx \frac{X_r}{\delta} + \frac{T_s}{\tau} \tag{4.10a}$$

or

$$N = \frac{X}{\delta} + \frac{T - X/V}{\tau} = \left(\frac{1}{\delta} - \frac{1}{V\tau}\right) X + \frac{T}{\tau} \tag{4.10b}$$

By denoting

$$a = \frac{1}{\delta} - \frac{1}{V\tau} \tag{4.11a}$$

and

$$b = \frac{1}{\tau} \tag{4.11b}$$

the variable portion of metered taxi fare is given by

$$F_c = CN \approx aCX + bCT \tag{4.12}$$

Note that by letting $A = aC$ and $B = bC$, Eq. (4.12) reduces to Eq. (4.7). Thus, if the parameters a and b, can be ascertained, the total metered taxi fare can be computed by

$$F = F_o + aCX + bCT \tag{4.13}$$

By substituting Eqs. (4.11) into Eq. (4.13)

$$F = F_o + \left(\frac{1}{\delta} - \frac{1}{V\tau}\right)CX + \frac{1}{\tau} CT \tag{4.14}$$

This is the fare equation when $\delta_o = \delta$ and $\tau_o = \tau$ are set for the taxi meter.[3]

[3] Ghahraman, D., et,al,, "Analysis of Metered Taxi Fares", Journal of Transportation Engineering, American Society of Civil Engineers, Vol. 101, No. TE4, 1975, pp. 807-816

Since some taxicab operators choose to set $\delta_o \neq \delta$ and $\tau \neq \tau_o$, it is necessary to modify Eq. (4.14) to take this fact into consideration. When $\delta_o \neq \delta$ and $\tau_o \neq \tau$, the meter trips the first time (n = 1) either after a distance δ_o has been traveled or a time τ_o has lapsed. If the distance δ_o is traveled in less time than τ_o, the fare for the entire trip can be computed by

$$F_1 = F_o + C + aC(X - \delta_o) + bC(T - \delta_o/V) \tag{4.15}$$

or

$$F_1 = F_o + (1 - \frac{\delta_o}{\delta})C + (\frac{1}{\delta} - \frac{1}{V\tau})CX + \frac{1}{\tau} CT \tag{4.16}$$

On the other hand, if the time τ_o lapses before the distance δ_o has been completed, the fare for the entire trip is obtained as

$$F_2 = F_o + C + aCX + bC(T - \tau_o) \tag{4.17}$$

or

$$F_2 = F_o + (1 - \frac{\tau_o}{\tau})C + (\frac{1}{\delta} - \frac{1}{V\tau})CX + \frac{1}{\tau} CT \tag{4.18}$$

Note that if $\delta_o = \delta$ and $\tau_o = \tau$, both Eq. (4.16) and Eq. (4.18) will be reduced to Eq. (4.14).

4.3 Interpretation of Taxi Fare Equations

Although taxicab owners, drivers and users recognize almost intuitively the contribution of total time elapsed T as well as the total distance traveled X to the total fare F of a trip, the above taxi fare equations represent a first attempt to provide an analytical framework to assess the weighting factors assigned to distance and time in fare calculation. As seen in Eq. (4.13), the parameters a and b are the weighting factors of distance and time respectively. Thus, the total fare F of a trip as accumulated in the taxi meter can also be computed by means of the taxi fare equations, provided that the speed V associated with the parameter a in Eq. (4.11a) can be determined.

Although a vehicle does not move at a constant speed V during the time periods of motion in the stop-and-go traffic as indicated in the idealized situation, accelerations and decelerations during these periods are insignificant, if V is regarded as the average speed over only those time periods during which a vehicle travels without stops. This speed, which is different from the average speed over all time periods comprising a ride, is refered to as the average running speed.

Since the average running speed V is a very important parameter in determining the relative weights of distance and time in fare calculation, it should be determined realistically from the types of travel that a vehicle is expected to experience over a period of time. Typically, the average running speed is smaller than "mean free speed" which refers to the speed of a vehicle in unimpeded motion, but is influenced by the speed limit of the road.

Thus, the speed limit must be properly modified to take into consideration possible accelerations and decelerations, in conjunction with information about the type of road, if it is to be used as a basis for determining the average running speed of a particular road. If the average running speed for each of the major road types having different speed limits is obtainable, the range of variation of average running speeds for various routes in a transportation network serving a city can be examined and its effects on metered taxi fare calculation can also be evaluated.

For the traffic conditions in most cities, the average running speed V is estimated to be 20 mph to 30 mph. The parameter a in Eq. (4.11a) is not very sensitive to the variation of V in this range. Two extreme cases are given as examples: (1) δ = 1/5 mile and τ = 1 minute, and (2) δ = 1/6 mile and τ = 2 minutes. The resulting values of parameters a and b obtained from Eqs. (4.11) for the two cases are respectively: (1) a = 5 - 60/V and b = 1, and (2) a = 6 - 30/V and b = 1/2, where a is expressed in 1/mile, b in 1/minute and V in mph. The relationship between a and V, and the corresponding value of b for both cases are shown in Figure 4.3. In the first case, time is given a relatively high weighting factor compared to that of distance, thus leading to a ratio of a/b = 2 for V = 20 mph and a/b = 3 for V = 30 mph; while in the second case, time is given a relatively low weighting factor compared to that of the distance, thus leading to a ratio of a/b = 9 for V = 20 mph and a/b = 10 for V = 30 mph. However, in each case, the variation of a/b in the specified range of V is not drastic.

An understanding of the relationship between the metered fare, F, and the possible linear combinations of total distance X and total time T is important for taxicab owners and public taxi regulatory agencies in making policy decisions. Presently, taxicab owners can set the distance increment δ and the time increment τ in any δ/τ ratio as long as the resulting fixed fare, F_0, and the incremental fare C, are within the limits approved by the regulatory agencies. Obviously, there is no good reason to set $\delta_0 \neq \delta$ and $\tau_0 \neq \tau$, and there is even less reason to set an incremental fare C for distance increment δ and a different incremental fare C_1 for time increment τ_1. Both of these practices tend to confuse the public and regulatory agencies. It is perfectly legitimate for a taxi operator to request a higher fixed fare F_0 to reflect the dispatching and other non-variable costs, or to request a higher weighting factor for the waiting time to account for the traffic congestion conditions. However, both of these issues should be examined within an analytical framework, and not settled in the hidden form of making δ_0 less than δ or C_1 different from C.

Although the development of these taxi fare equations has been motivated by the desire to calculate taxi fares prior to a trip, the analytical framework as represented by Eq. (4.14) offers a useful means to examine the equity and efficiency of any proposed pricing structure. Given a set of rates F_0 and C with the associated values of δ and τ, the total fares for a number of trips with a wide range of assumed distance X and time T can actually be calculated on the basis of a realistic value of V corresponding to local traffic and road conditions. Then, the regulatory agency can critically analyze the effects of F_0/C ratio and δ/τ ratio in the proposed pricing structure on various types of trips in terms of estimated distance and time.

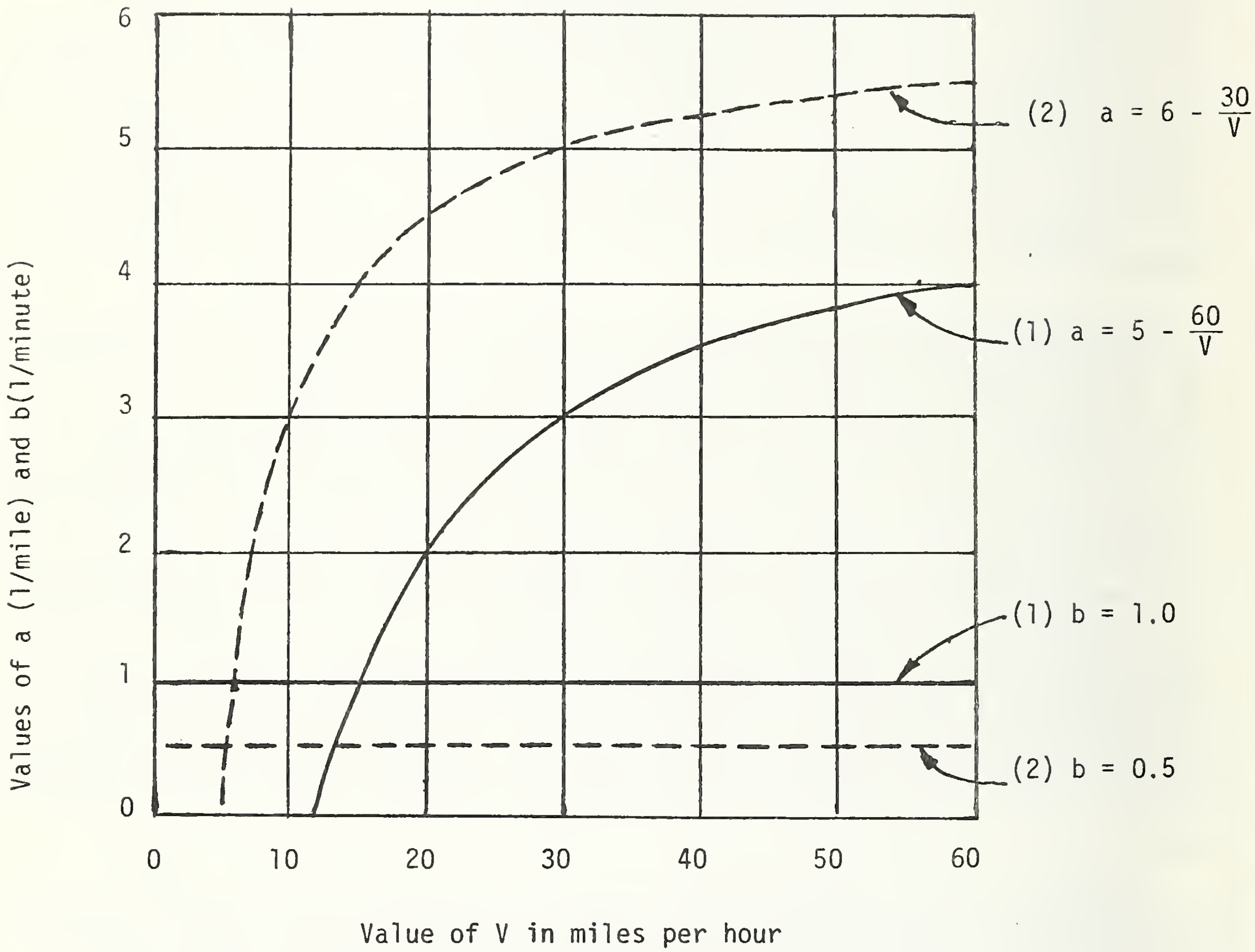


Figure 4.3

VARIATION OF PARAMETERS IN TAXI FARE CALCULATION

4.4 Distance and Time Data Requirements

Since the RSVP System is designed to calculate fare prior to a trip, it is necessary to estimate reliably the distance and time for any trip between a specified origin and destination on the basis of the information for the transportation networks in the service area. Data files for such networks developed by Metropolitan Planning Organizations (MPO) are particularly useful because they are readily available and are generally accepted by the public as unbiased. For the Pittsburgh area, the information is available from the Southwestern Pennsylvania Regional Planning Commission (SPRPC).

The Time/Distance File developed by the SPRPC provides centroid-to-centroid distance, unrestrained (off-peak) time and restrained (peak) time for all possible pairs of traffic zones in the service area. For the purpose of data validation, a statistical analysis was conducted to examine the possibility of significant linear dependence between distance and unrestrained time, between distance and restrained time, and between unrestrained and restrained time. The results indicate that off-peak time can be reliably estimated from peak time and conversely. However, the Time/Distance File consists of both off-peak time and peak time as well as distance for all zone-pairs in the service area. This allows for dynamically changing time and distance data to indicate temporary traffic congestion and road closings and openings.

Correction factors are devised to estimate distance and time for an arbitrary origin-destination (o-d) pair. Suppose that:

p = the origin in zone i whose centroid is c_i

q = the destination in zone j whose centroid is c_j

d(p,q) = the airline distance between p and q

$d(c_i, c_j)$ = the airline distance between c_i and c_j

e_{ij} = the distance of a ride between c_i and c_j

u_{ij} = the off-peak time of a ride between c_i and c_j

r_{ij} = the peak time of a ride between c_i and c_j

X = the distance of a ride between p and q

T = the off-peak time of a ride between p and q

Z = the peak-time of a ride between p and q

Then, the distance, off-peak time and peak time of a ride between the centroids of zones i and j can be adjusted by considering the relation of the airline distance between p and q and that between the centroids of zones i and j. Simple correction factors have been computed to adjust distance

and time, and are validated by means of regression against actual ride distance and time collected by cab drivers on their daily routes.

If the ride is an interzonal ride, $i \neq j$, as shown in Figure 4.4, the estimated distance, off-peak time and peak time are respectively given by

$$X = \left[\frac{e_{ij}}{d(c_i,c_j)}\right] d(p,q) \tag{4.19a}$$

$$T = \left[\frac{u_{ij}}{d(c_i,c_j)}\right] d(p,q) \tag{4.19b}$$

$$Z = \left[\frac{r_{ij}}{d(c_i,c_j)}\right] d(p,q) \tag{4.19c}$$

Thus, the correction factors in brackets represent respectively distance, off-peak time and peak time per unit air-line distance for the zone pair i,j. Note that the terms in the brackets can be precomputed and stored, while d(p,q) is variable with each ride.

On the other hand, if the ride is intrazonal, $i = j$, and similar factors are defined by considering the zones $k \in S_i$ adjacent to zone i where S_i is the set of adjacent zones and N_i the number of such zones as shown in Figure 4.5. Then,

$$X = \left[\frac{1}{2N_i} \sum_{k \in S_i} \frac{e_{ik} + e_{ki}}{d(c_i,d_k)}\right] d(p,q) \tag{4.20a}$$

$$T = \left[\frac{1}{2N_i} \sum_{k \in S_i} \frac{u_{ik} + u_{ki}}{d(c_i,c_k)}\right] d(p,q) \tag{4.20b}$$

$$Z = \left[\frac{1}{2N_i} \sum_{k \in S_i} \frac{r_{ik} + r_{ki}}{d(c_i,c_k)}\right] d(p,q) \tag{4.20c}$$

Intrazonal correction factors are assumed to be independent of the zone, as justified by the inspection of these factors derived from the distance/time data. Therefore, some reasonable values have been prescribed for these factors in all zones.

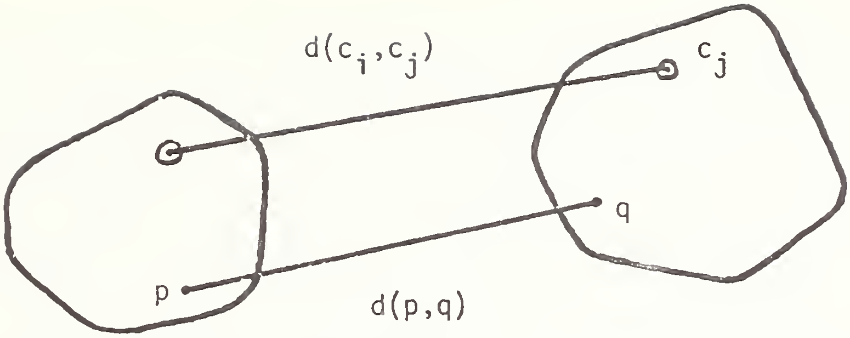
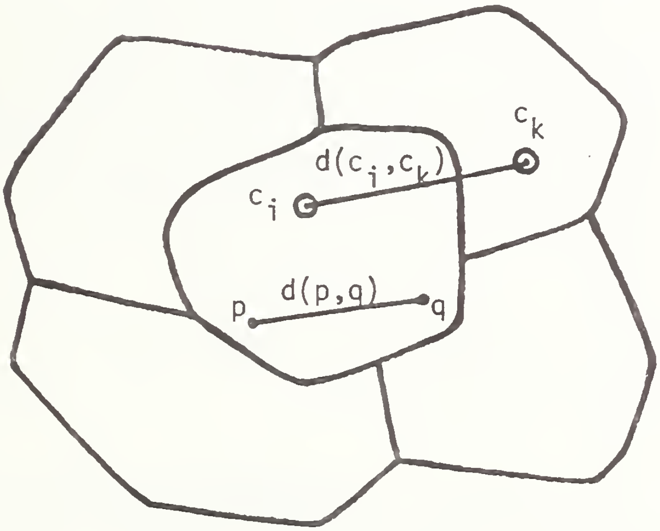


Figure 4.4

INTEPZONAL ADJUSTMENT



$k \in S_i \ (k = 1,2,\ldots,N_i)$

Figure 4.5

INTRAZONAL ADJUSTMENT WITH RESPECT TO ADJACENT ZONES

4.5 RSVP Exclusive and Shared Ride Formulas

The RSVP System is designed to calculate fares for exclusive ride and shared ride taxi services on the basis of a set of theoretically verifiable formulas and a well-defined data base. Thus, a consistent fare for a specific trip, whether it is provided by exclusive ride or shared ride taxi service, can be computed in advance and guaranteed. Through the use of advanced technology for computation, communication and control in taxi operations, the RSVP System also has inherent real time audit capabilities. It permits efficient and equitable fare calculations and at the same time provides management and regulatory authorities with more accurate information than has heretofore been possible.

In the case of exclusive ride taxi during service, the fare calculated in advance by the RSVP System reflects the actual fare which would have been accumulated in the taxi meter during. The schedule of rates for the fixed fare "flag drop" and the incremental fare for each "tripping" of the meter and the associated distance increment and time increment in general must be approved by a regulatory agency for the RSVP System taxi service as for the conventional taxi service. In addition, the fare calculation formula which represents the analytical relationship between the schedule of rates and the time/distance data must also be approved.

In the case of shared ride taxi service, fares are structured such that each passenger pays an equitable portion of the cost of the service. Specifically, the fare for each passenger is based upon a discount from the fare which would be charged if normal taxicab service had been requested. If two or more passengers having the same origin and destination request shared ride service, the total fare will be a discounted fare for one person, plus a surcharge for each additional person in the group. Since point-to-point distances and times for direct trips are used to compute normal exclusive ride fares, customers are not penalized for route deviations which occur in shared ride service. The surcharge for each additional passenger in any group having the same origin and destination is necessary since in shared ride taxi service the number of vacant seats is a critical parameter (i.e., it determines whether the vehicle is still potentially shareable). At the time of a request for service, a customer is informed of the least expensive class of service, the estimated time before a vehicle would be available, and the estimated travel time for exclusive taxicab service.

The use of a discount from exclusive taxi fares reflects that individual passengers should be compensated for the route deviations which result from shared ride operations: furthermore, since this approach is based upon the fare structure for traditional exclusive ride service, it should be more readily accepted by regulatory agencies. Clearly, discounts must not dilute total revenues to the extent that the service becomes unprofitable; thus, equilibrium discount levels should be determined from monitored experiments. At the outset, any uncertainties concerning market potential should be resolved by initially choosing conservative discount levels.

The exclusive ride taxi fare calculation for the RSVP System is based on Eq. (4.14). Since the adjusted distance obtained from the Time/Distance File is expressed in multiples of δ miles, the adjusted distance X_δ is equal to X/δ where X is the total distance in miles. Then, the exclusive ride fare is given by the formula.

$$F = F_o + (1 - \frac{\delta}{V\tau}) CX_\delta + \frac{1}{\tau} CT \tag{4.21}$$

where

X_δ = the adjusted distance (in multiples of δ miles) obtained from the Time/Distance File;

T = the adjusted time (in minutes) obtained from the Time/Distance File.

Based on the current rates of F_o = 80 cents, C = 10 cents, $\delta_o = \delta = 1/6$ mile, $\tau_o = \tau = 1$ minute, and the average running speed V = 20 mph, the RSVP System exclusive ride fare calculation formula becomes:

$$F = 80 + 5X_\delta + 10T \tag{4.22}$$

Shared ride taxi fares are computed as discounts from the point-to-point fares which would have been charged had passengers chosen exclusive ride taxi service. Different discount levels may be specified for different types of sharedride services. Since each passenger in shared ride service will occupy a seat which can no longer be used to serve another passenger, the number of persons in a party having the same trip origin and destination must be included in the shared ride fare calculation formula. Then, the shared ride fare for a party having the same trip origin and destination is given by the formula:

$$F_s = (n - 1)S + (1 - k)F \tag{4.23}$$

where

n = number of persons in a party having the same trip origin and destination;

S = surcharge for each additional passenger in the party having the same trip origin and destination;

k = discount (in percent) for the specified type of share ride service;

F = point-to-point fare for the party having the same trip origin and destination as computed by the exclusive ride fare calculation formula, Eq. (4.21).

Note that for a single person participating in shared ride, $(n - 1)S = 0$, and F_s is the shared ride fare for that person. On the other hand, if a party

of several persons having the same trip origin and destination occupies the entire taxicab without sharing with other groups, this party will be advised to pay the smaller of the two fares as computed by Eq. (4.21) and Eq. (4.23). Based on the current schedule of rates and 10% discount for shared ride (plus 50 cents for each additional passenger having the same trip origin and destination), the RSVP System shared ride fare calculation formula becomes:

$$F_s = 50(n - 1) + 72 + 4.5X_\delta + 9T \qquad (4.24)$$

4.6 Alternative Fare Policies for Shared Ride

Some inequity is inherent in any shared ride fare calculation mechanism. Consequently, a variety of alternative policies for shared ride fares should be examined to prevent exclusive taxi fares from becoming the only basis for deriving future shared ride fares. Due to route deviations, shared ride fares computed as discounts from exclusive taxi fares imply that passengers in the shared ride mode pay for time at a different rate than do exclusive service passengers. Even an additional adjustment based upon the number of persons actually in the vehicle does not always adequately compensate for the delay and inconvenience which individual riders may experience.

In this vein it is important to distinguish between inequities as perceived by passengers and inequities as perceived by operators. For example, zone systems with relatively large discrete fare increments are regarded with suspicion by most users but are typically accepted by operators since cost discrepancies tend to average out over a large number of trips. This perceived inequity may be minimized by reducing the size of the zones, even down to the level of city blocks as proposed by Kirby.[4] Conceptually, however, such a fine grid would differ little from the standard metered fare since fares would be determined by selecting a minimum path through contiguous zones and computing the total fare by summing the increments from each zone. Except for the absence of a time charge, this technique simulates a meter by measuring fare increments graphically rather than by a connection to the drive train of a vehicle. Similarly, such a zone technique simulates the distance portion of the RSVP System fare calculation algorithm; thus any time charge policy which might be applicable for zone systems could also be implemented in the RSVP System.

From a passenger's perspective, the most logical basis for fare calculation would be in terms of utility to the customer rather than in terms of the cost to the operator to provide the service. Thus, a trip involving a longer distance (i.e., deviation) due to shared ride would be compensated by a reduction in fare, whereas trips which require little time would be charged higher fares. Essentially, this concept would imply a fare structure which is directly proportional to distance and inversely proportional to time. However, a number of issues related to dispatching and driver attitude as well as fare calculation need to be resolved before shifting the emphasis from a cost-of-service basis to a level-of-service basis.

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[4] Kirby, R.F., A Grid Fare Structure for Shared Taxi Services (Working Paper 505-2-7), The Urban Institute, Washington, D.C., June 1976.

5. DATA BASE MANAGEMENT SYSTEM

5.1 Overview

The Data Base Management System provides a control structure which links processing modules and data files in the RSVP System. Currently, it includes:

(1) A file structure for travel times and distances between zones in the service area;

(2) A file structure for state plane coordinates for all street addresses in the service area;

(3) Subroutines for obtaining and validating trip data, computing and displaying fare information, and interpreting and executive commands.

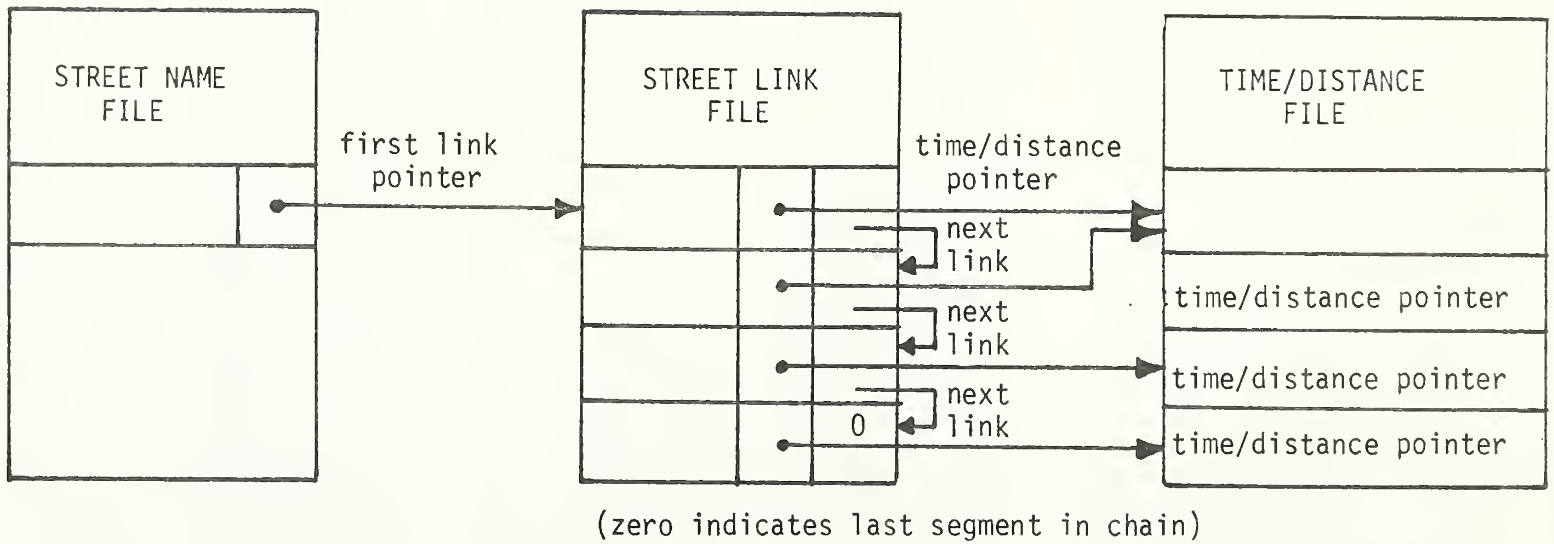
The Time/Distance File, originally developed by the Southwestern Pennsylvania Regional Planning Commission (SPRPC) as an aid for transportation planning, contains shortest-time-path distances, travel times during uncongested periods, and travel times during congested periods for trips between all possible pairs of traffic zones. The Address-Coordinate File, also developed by the SPRPC, associates state plane coordinates with all street addresses in Allegheny County, Pa. The file contains 18,308 unique streets which are referenced to 456 traffic zones.

The primary function of the Data Base Management System is to compute and display fares and estimated times for trips with a specified origin and destination. To insure reasonable system response times, as expansions are implemented, console input subroutines are interrupt-driven, and disk files are organized to minimize read/write head movement. For future system optimization, a count field is reserved in each file record to permit periodic file reorganization based upon record activity.

The Address-Coordinate File consists of two distinct components: A Street Name File and a Street Link File. Each Street Name record contains a pointer to a chain of link records; each link record contains the state plane coordinates for a particular set of address ranges on the street, and a pointer to a record in the Time/Distance File. Each record in the Time/Distance File contains travel data for trips from the given origin zone to all other zones. These file linkages are shown in Figure 5.1. The fare calculation for a specific trip requires obtaining origin and destination coordinates, retrieving and adjusting the appropriate distances and times, computing the fare, and displaying the results.

RSVP System tasks are executed as subroutines called by a main program. An overview of these relationships is shown in Figure 5.2. The main program executes a round-robin polling sequence until a flag associated with an Operations Console indicates that it is requesting some action. At such time, the polling sequence is terminated and the action is initiated. The PDP-11 architecture permits essentially unlimited nesting of interrupts, thus the overall data entry and task interpretation/execution process is performed rapidly without wasting CPU cycles while and operator is entering data.

The Data Base Management System can accomodate up to 4 Operations Consoles when at least 16K words of memory are available.



Not all street links for a given street necessarily point to the same record in the Time/Distance File. Some streets have links in several traffic zone.

Figure 5.1

RSVP SYSTEM FILE ORGANIZATION

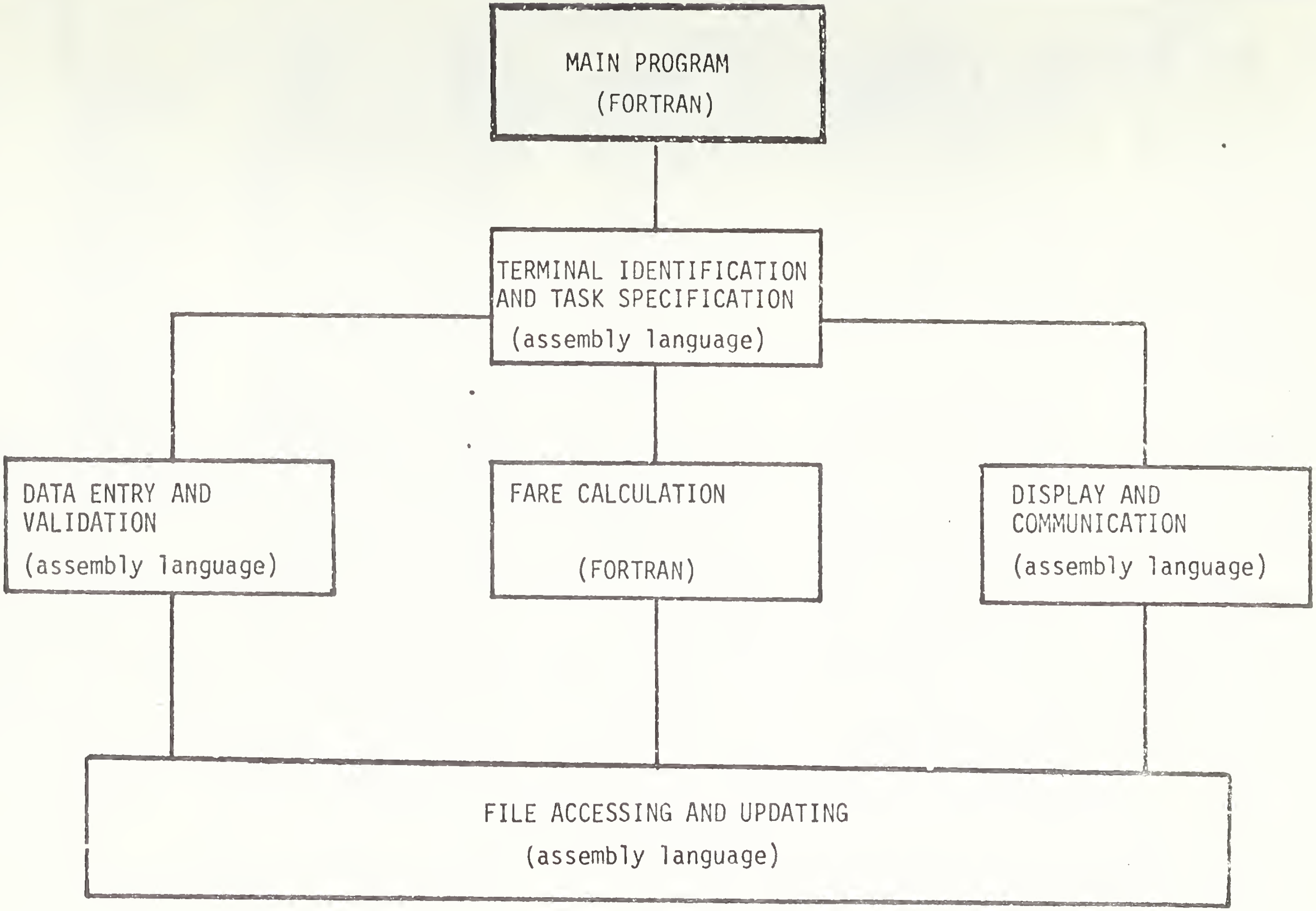


Figure 5.2

DATA BASE MANAGEMENT SYSTEM

5.2 Data Acquisition and Validation

The data for the Time/Distance File were derived from an analysis of traffic flow patterns between traffic zones defined by the Southwestern Pennsylvania Regional Planning Commission (SPRPC). These zones encompass the entire six-county region served by the SPRPC, and were created specifically to aid transportation planning activities. In general, traffic zones were defined to reflect existing physical boundaries (e.g., main arterials, rivers, bridges, etc.), existing political boundaries, socio-economic characteristics, and travel patterns. The traffic zones in the six-county region are shown in Figure 5.3.

These traffic zones served as the basis for a network representation of the area, and traffic assignment computer programs developed by the U.S. Bureau of Public Roads were used to compute the shortest-time-path distance between every possible pair of zones. In addition, two separate travel times were computed: one representing the travel time under normal off-peak conditions, and one representing travel time under somewhat congested conditions. To validate the results, samples of the computed values were compared with actual travel time and distance data collected in an extensive traffic survey conducted in 1967,[5] appropriate adjustments were made in the parameters of the traffic assignment programs, and the files were reconstructed. This process was repeated several times prior to final SPRPC approval of the files for general use in transportation planning.

The Address-Coordinate File for the RSVP System is based upon an Address Coordinate Guide File also developed and maintained by the SPRPC. Prior to any editing, each record in the file contained a street name, a street type (e.g., ST, AV, RD, etc.), the zip code, a low address and a high address for the particular link (where a link correponds roughly to the length of a city block), an odd or even street side indicator, the traffic zone number for the link, and the X and Y state plane coordinates of the midpoint of the link.

Preliminary computer validation and compression of this data consisted of removing duplicate records, checking all records for valid characters, and reducing the size of the file by combining odd and even street links where appropriate. For example, if the high and low addresses of two links on opposite sides of a street differed only by one, then the street address ranges were combined and the coordinates averaged. (Whenever links were combined, the coordinates and traffic zones of each link were checked for consistency. If the difference between coordinates was greater than 500 feet, or if the traffic zone numbers were unequal, the combined link was flagged to be verified later.) This initial analysis also produced a list of types in the file, and from this list a set of standard types was developed for eventual application to the entire file.

To help insure the use of valid coordinates for specific addresses when a customer supplies incorrect information, some streets have multiple records which differ only in one filed (e.g., zip code or type). Thus, if a customer inadvertently gives the wrong zip code, the system can still access the file without error and computer the correct fare. In addition, unique streets in the

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5 Calibration of the 1967 Arterial Highway Network for the Southwestern Pennsylvania Region, Southwestern Pennsylvania Regional Planning Commission, Pittsburgh, Pa. 1971.

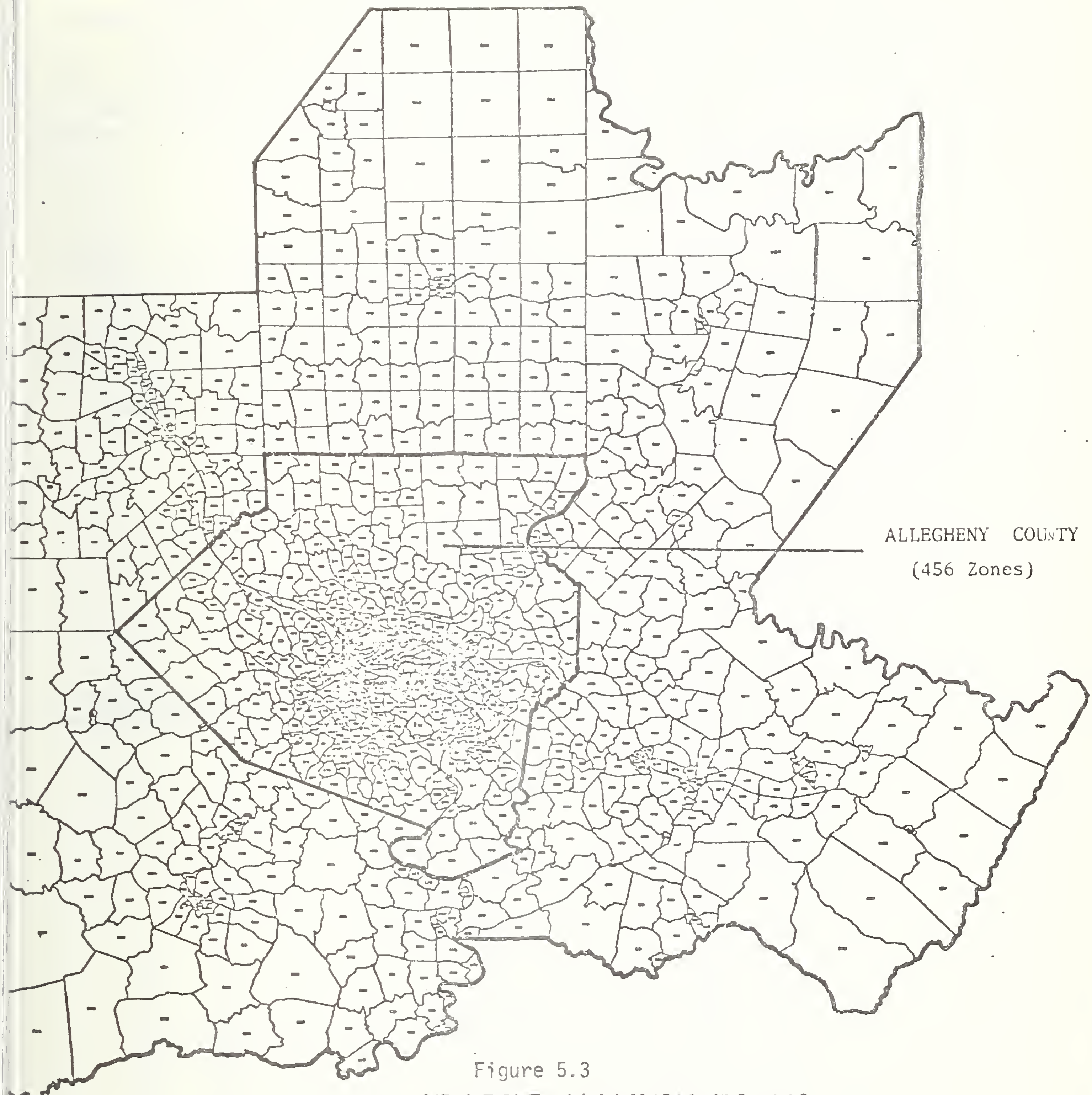

Figure 5.3

TRAFFIC ANALYSIS ZONES
SIX-COUNTY BASE MAP

(986 Zones)

file are flagged. Thus, if a street number and name are entered and are unique, the operator need not enter the entire address; the system will display missing data and continue to prompt for the next required information. Finally, remedy errors resulting from misspelled street names or incorrect input formats, the System Operator has a computer listing of all streets in the file. In short, RSVP System files are derived from data compiled and validated by a competent and reliable public agency. To provide additional validation, computer simulations of a variety of different operating conditions have been undertaken and the results compared with actual trip data (current and historical) from Peoples Cab Company.

5.3 Data Structures and File Organization

Records in the Street Name File are assigned to disk locations by a hashing algorithm. The initial algorithm simply treats six characters from a street name as three 16-bit integers and multiplies them together. Sixteen bits are masked from the result and are used to specify an absolute disk location for one "bucket." Up to 39 street names can be stored in one bucket without causing overflow. When overflow occurs, the extra records are placed in overflow buckets that were specified after analyzing the distribution at calculated disk addresses for the entire fill. The format of each type of record is shown in Figure 5.4. A record in the Street Name File contains:

(1) The street name;

(2) The street type;

(3) The last three digits of the zip code;

(4) A field for a frequency-of-use count;

(5) A pointer to the first street link for the street.

The Street Link File consists of linked lists of records which contain the address and coordinate information of streets. The format of each record is:

(1) Low street address in the link;

(2) High street address;

(3) State plane X-coordinate of the midpoint;

(4) State plane Y-coordinate of the midpoint;

(5) Usage count of the record;

(6) Traffic zone number for the link;

(7) A special flag used by software;

(8) Pointer to the next link (or 0 if last link).

STREET NAME RECORD (26 bytes)

NAME	TYPE	ZIP CODE	USAGE COUNT	POINTER TO FIRST LINK
(18)	(2)	(2)	(2)	(2)

STREET LINK RECORD (16 bytes)

LOW ADDRESS	HIGH ADDRESS	X COORDINATE	Y COORDINATE	USAGE COUNT	POINTER TO TIME/DIST.	FLAG	POINTER TO NEXT LINK
(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)

TIME/DISTANCE RECORD (7300 bytes)

CENTROID X COORDINATE	CENTROID Y COORDINATE	DISTANCE	OFF PEAK TIME	PEAK TIME	ACT. DISTANCE	ACT. OFF-PEAK TIME	ACT. PEAK TIME	OFF PEAK COUNT FIELD	PEAK COUNT FIELD
(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)

This portion of record is repeated for each zone

Figure 5.4

RSVP SYSTEM RECORD FORMATS

Conceptually, the Time/Distance File may be viewed as an 456 x 456 matrix containing information about all possible trips among the zones. Element (i,j) in record i refers to a trip originating in zone i and terminating in zone j. The first two fields in record i contain the state plane coordinates of the centroid[6] of zone i; the remaining fields contain the zone-pair distances and times.

Each element (i,j), i ≠ j, in record i refers to inter-zonal trips from zone i to zone j and consists of sub-fields containing the following:

(1) Shortest-time-path centroid-to-centroid distance;

(2) Off-peak centroid-to-centroid time;

(3) Peak centroid-to-centroid time;

(4) Accumulated actual trip distances;

(5) Accumulated actual off-peak trip times;

(6) Accumulated actual peak trip times;

(7) Off-peak trips count sub-field;

(8) Peak trips count sub-field.

In element (i,i), the first six sub-fields are average quantities for intra-zonal trips in zone i. The last two sub-fields are count fields for off-peak and peak trips within zone i. The sub-fields (4) - (6) in the Time/Distance File are used to periodically update the subfields (1) - (3).

The Address-Coordinate and Time/Distance Files are organized to minimize read/write arm movement when retreiving trip information. Conceptually, the physical disk drive is divided into cylinders, with four tracks in each cylinder. Read/Write heads are thur positioned over four tracks simultaneously when a given cylinder is accessed as shown in Figure 5.5.

The disk storage allocation of the files is represented in Figure 5.6. For simplicity, the interleaved units of the fixed and the removable disks have been shown separately. Unit 0 is used by the RT-11 Operating System to store language processors and utility programs as well as the RSVP System programs. The other three units store the Address-Coordinate and Time/Distance Files and are accessed by the RSVP System Programs without using RT-11 accessing techniques. RSVP System data files require 3,313,184 16-bit words of disk storage.

5.4 Documentation

Actions requested by Operations Consoles are represented internally by task numbers. A buffer area is reserved for each Operations Console and the condition of each status flag is continuously monitored to determine if action is being requested. The memory map of the area required for each Operations

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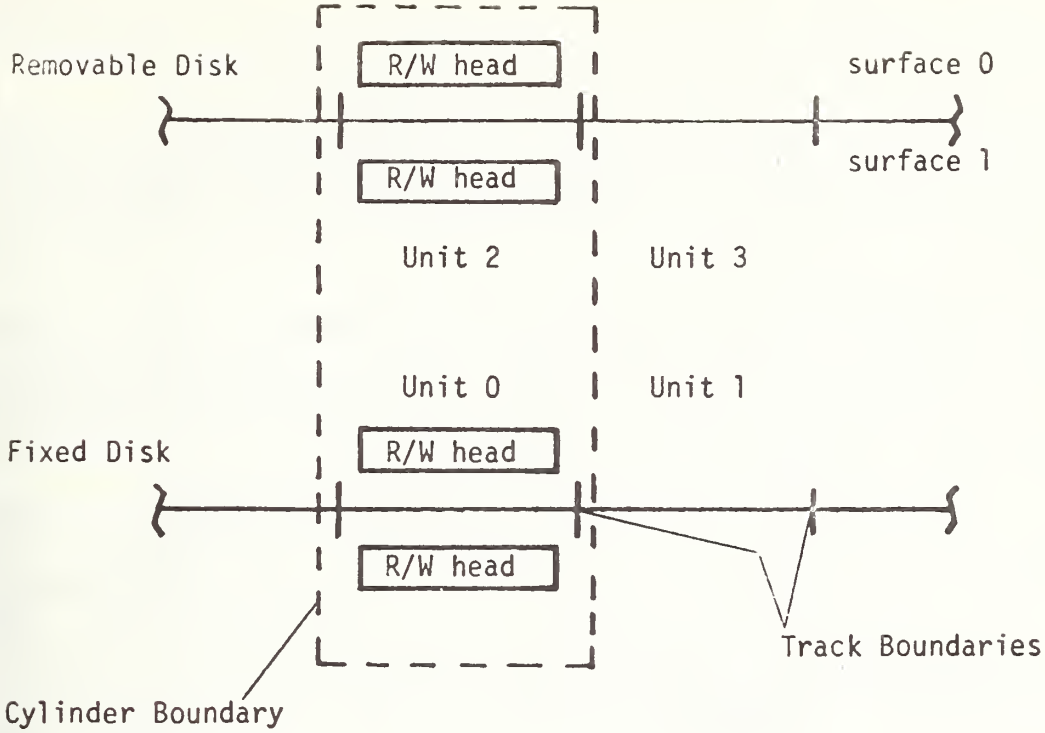
[6] The centroid of a zone is the location which was judged by SPRPC to be its most logical "center of development." Centroid coordinates were used as network node coordinates in the traffic assignment computer programs.



Tracks on each disk are referenced by alternate even or odd-numbered units (two units per disk). Controller logic positions Read/Write heads over four tracks simultaneously.

Figure 5.5

RSVP SYSTEM DISK STORAGE

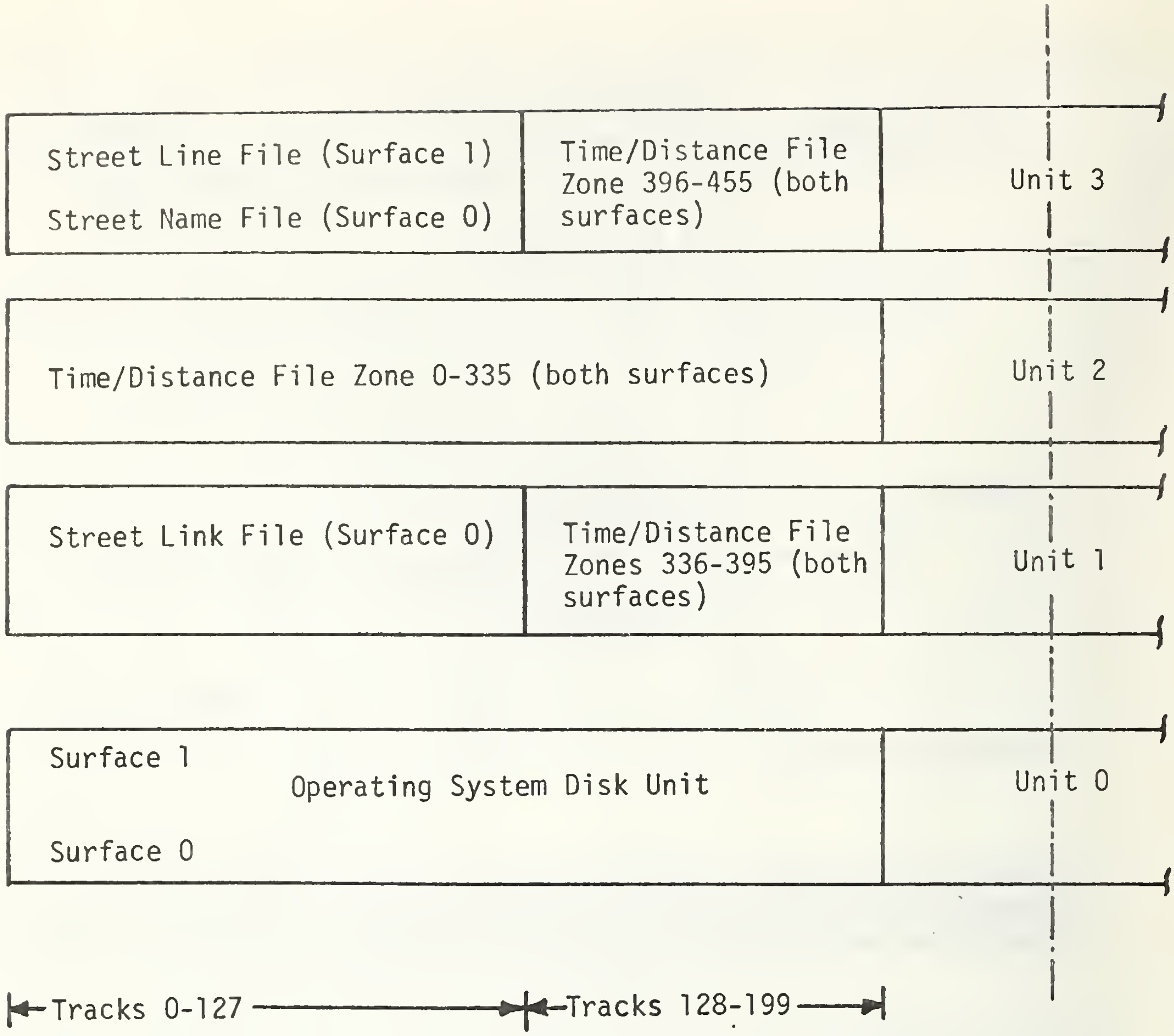


Figure 5.6

RSVP SYSTEM FILE STORAGE ALLOCATION

Console is shown in Table 5.1. When a status flag indicates that action is requested, the Operations Console requesting the action is identified and the action is initiated. The possible tasks are summarized in Table 5.2.

In general, an action is initiated either by the conclusion of a previous task or by an explicit command issued from an Operations Console. Valid commands that can be issued from an Operations Console are given in Table 5.3. The Escape key may be struck at any time to instruct the program to prompt for command.

The command to display System Information causes the program to print, by type of service, the number of trips, number of passengers, number of paid miles and the revenue to date. In addition, the totals of these quantities are also displayed for online management inquiry. Vehicle Information is displayed in a similar format for the specified vehicle number.

Trip data is obtained by prompting first for the origin address. If an invalid address is entered, the cause of error is reported and the address is requested to be entered again. When a valid origin address is provided, the program prompts for the destination address which is also validated. A simplified flowchart of street address validation is presented in Figure 5.7. After requesting and obtaining the number of passengers, the estimated trip time, distance and fare for each class of service is displayed. The operator can then enter the type of service requested or strike the Escape key to cancel the request if none is required. If immediate service is requested, the program prompts the Operator to assign a vehicle for the Trip. The fare and estimated trip time are subsequently communicated to the microprocessor Interface Console which transmits the information to the assigned vehicle. The format of the memory area where trip data are stored is shown in Table 5.4. Trip data entry is summarized in Figure 5.8.

In entering street address, the type (ST, AV, etc.) or zip code may be omitted. The program determines if the available information uniquely identifies a street in the Street Name File. In this case, the missing information is inserted in the address display for visual validation by the operator. Otherwise, the complete street address will be requested.

TABLE 5.1

OPERATIONS CONSOLE BUFFER MAP

FIELD NAME	LENGTH (bytes)	USE/DESCRIPTION
CONFLG	2	Console status flag to indicate that console requires action
MSGFLG	2	Message status flag to indicate a message for console
CHRCNT	2	Character count for current input string from console
ORGNAM	2	Disk address for origin street name
—	2	Offset in disk bucket to specific street name
ORGLNK	2	Origin Street Number (binary representation)
DSTNAM	2	Disk address for destination street name
—	2	Offset in disk bucket for specific street name
DSTLNK	2	Destination street number (binary representation)
CFARES	8	Storage area for computed fares (number of nickels)
		Exclusive, shared, planned, subscription
TENTHS	2	Computed mileage (number of tenth miles)
VEHNBR	2	Vehicle assigned to trip (index in vehicle file)
CNTTYP	2	Low order byte: number in party
		High order byte: type of service
LOGTIM	2	Time service request was logged
TRIPID	12	Trip identification (10 character name and a binary number)
PHONE	10	Customer's phone number
NEWCMD	4	Buffer area for command input string
DATBUF	60	Buffer area for address input string
DSKBUF	1024	Buffer area for disk accesses
HSHFLD	22	Buffer area for characters for street name hashing

Table 5.2

RSVP SYSTEM TASKS

TASK	ACTION
0	Terminate the RSVP System program
1	Obtain street address from Operations Console
2	Verify street name and number
3	Obtain number of passengers
4	Compute and display fares for all classes of service
5	Obtain type of service requested
6	Communicate fare and estimated trip time to vehicle
7	Update System and Vehicle Information
8	Display System Information
9	Obtain vehicle number for display
10	Display Vehicle Information

Table 5.3

SYSTEM COMMANDS

COMMAND	ACTION
ST <CR>	Stop the RSVP Program
DS <CR>	Display System Information
DV <CR>	Display Vehicle Information
<CR>	Prompt for Trip Data
<ESC>	Prompt for Command

Note: <CR> and <ESC> denote the RETURN and ESCAPE keys on an Operations Console keyboard.

TABLE 5.4

PROPOSED TRIP FILE RECORD FORMAT

FIELD NAME	LENGTH (bytes)	USE/DESCRIPTION
ORGFLD	8	Disk location for origin address
DSTFLD	8	Disk location for destination address
NUMBER	1	Number of passengers
SVCTYP	1	Service type
CHARGE	2	Fare charged (number of nickels)
DATLOG	2	Date logged
TIMLOG	2	Time logged
TERMED	2	Console identification
RQTDAT	2	Date service requested
RQTTIM	2	Time service requested
SVCDAT	2	Date service performed
SVCTIM	2	Time service performed
ASSIGN	2	Vehicle assigned
CUSTOM	16	Customer name
TELPHN	8	Customer telephone number

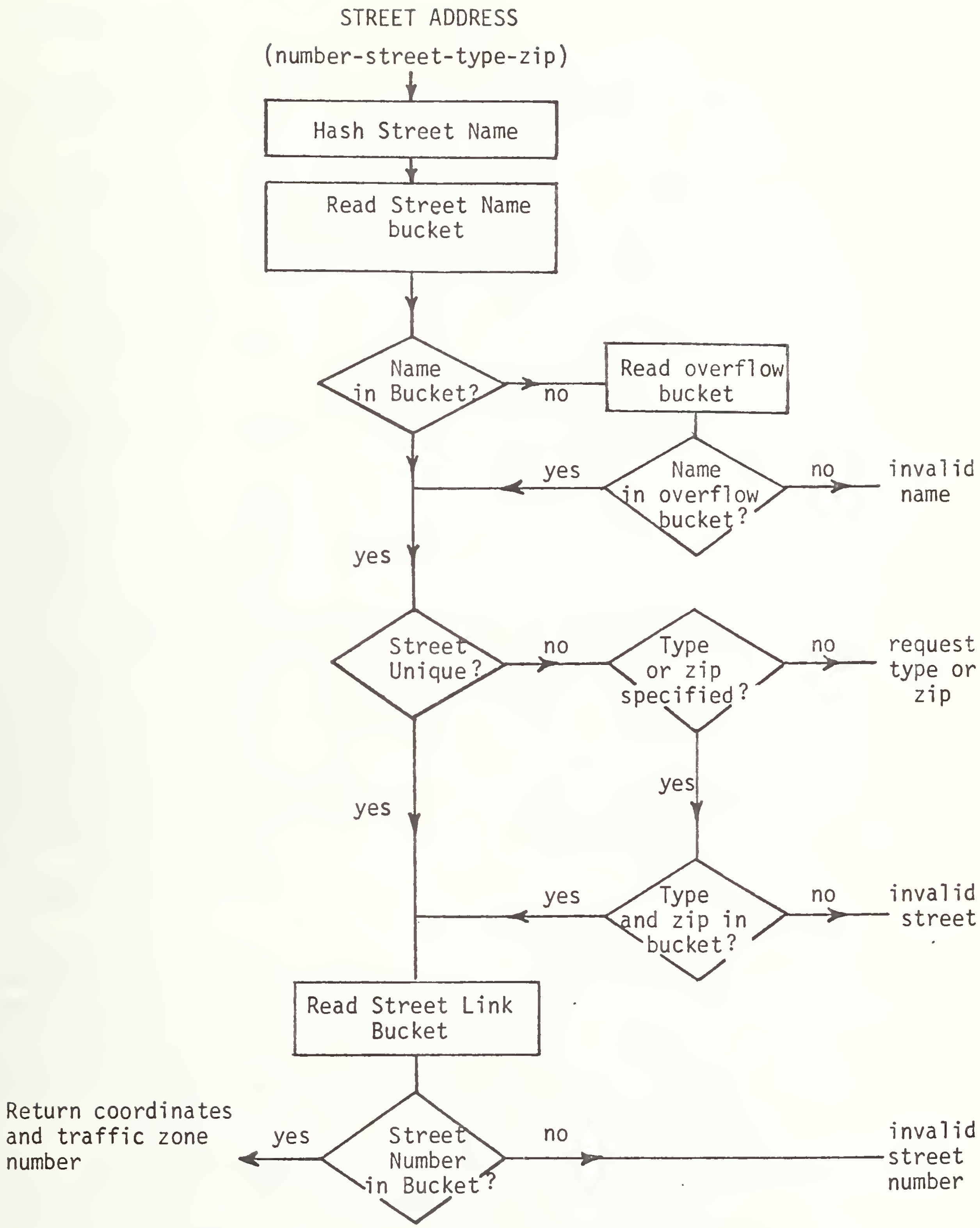


Figure 5.7

ADDRESS VALIDATION

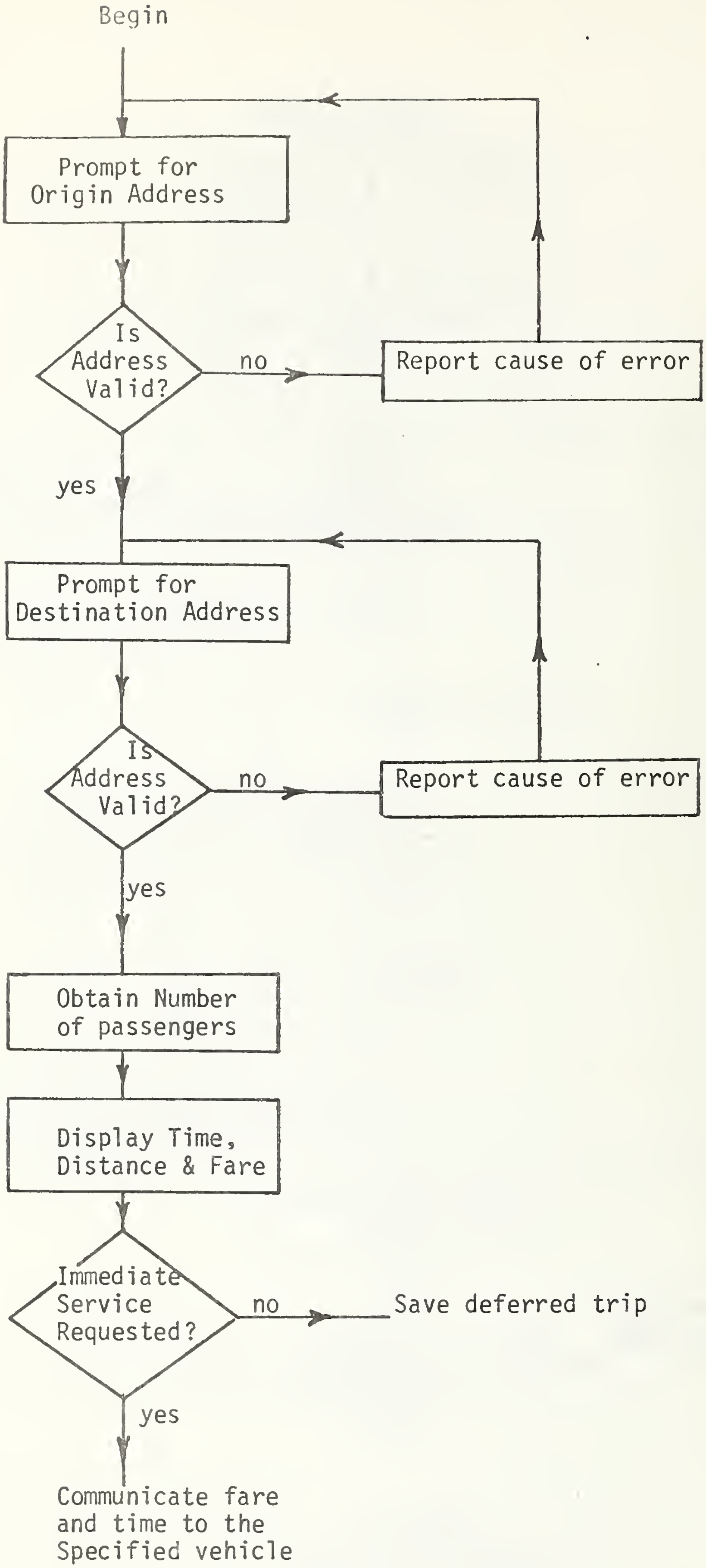


Figure 5.8
TRIP DATA ENTRY

6. CONTROL CENTER

6.1 Overview

The RSVP System Control Center is the focal point for all operations. Basic hardware components are:

(1) The Central Computer, linked to a Master Console, a hard copy device and a cartridge disk storage unit;

(2) An Operations Console for entering trip data and displaying System information;

(3) A microprocessor-based Interface Console, consisting of an 8080 microprocessor, a bidirectional modem, a high power VHF FM radio transceiver, and an auxiliary keyboard.

Basic software components consist of vendor-supplied language processors, utility programs, and an operating system, in addition to the RSVP System Data Base Management System.

The RSVP System Control Center is located at the Peoples Cab Company. A telephone link has been established with the Computation Center at Carnegie-Mellon University to permit high speed data transfers over the dial-up telephone network.

Taxi service from the RSVP System is requested either through a telephone call from a customer or by a radio message from a driver who has been hailed on the street. The Operator enters trip data via the Operations Console and initiates a routine which calculates the fare and estimated trip time. The results are displayed on the Operations Console and communicated to the customer; if service is desired, the Operator specifies which vehicle will provide the service and initiates transmission of trip data to the appropriate vehicle. The Interface Console stores trip data in a buffer, transmits data to the vehicle, and verifies that data has been received.

6.2 Central Computer System

The Central Computer System consists of a DEC PDP-11/10 minicomputer with 16K words of core memory, a real-time clock, and an Extended Arithmetic Element to permit fixed point integer multiplication and division operations. System peripherals include a cartridge disk system with a capacity of five million words, a DECwriter terminal which serves as the Master Console and a hardcopy device, and a CRT terminal which serves as an Operations Console. The Central Computer System and pheripherals are shown in Figure 6.1

Due to the limited main memory capacity and the necessity for fast program execution, most RSVP System software is coded in PDP-11 assembly language, although the main control program is coded in FORTRAN. The data Base Management System is initiated via the vendor-supplied operating system (RT-11); however, after initiation, the Data Base Management System functions in a stand-alone mode and controls all computer resources. Other vendor-supplied programs such as the text editor, the FORTRAN compiler, the Assembler, and a file maintenance program are also required to support continuous RSVP System software development.

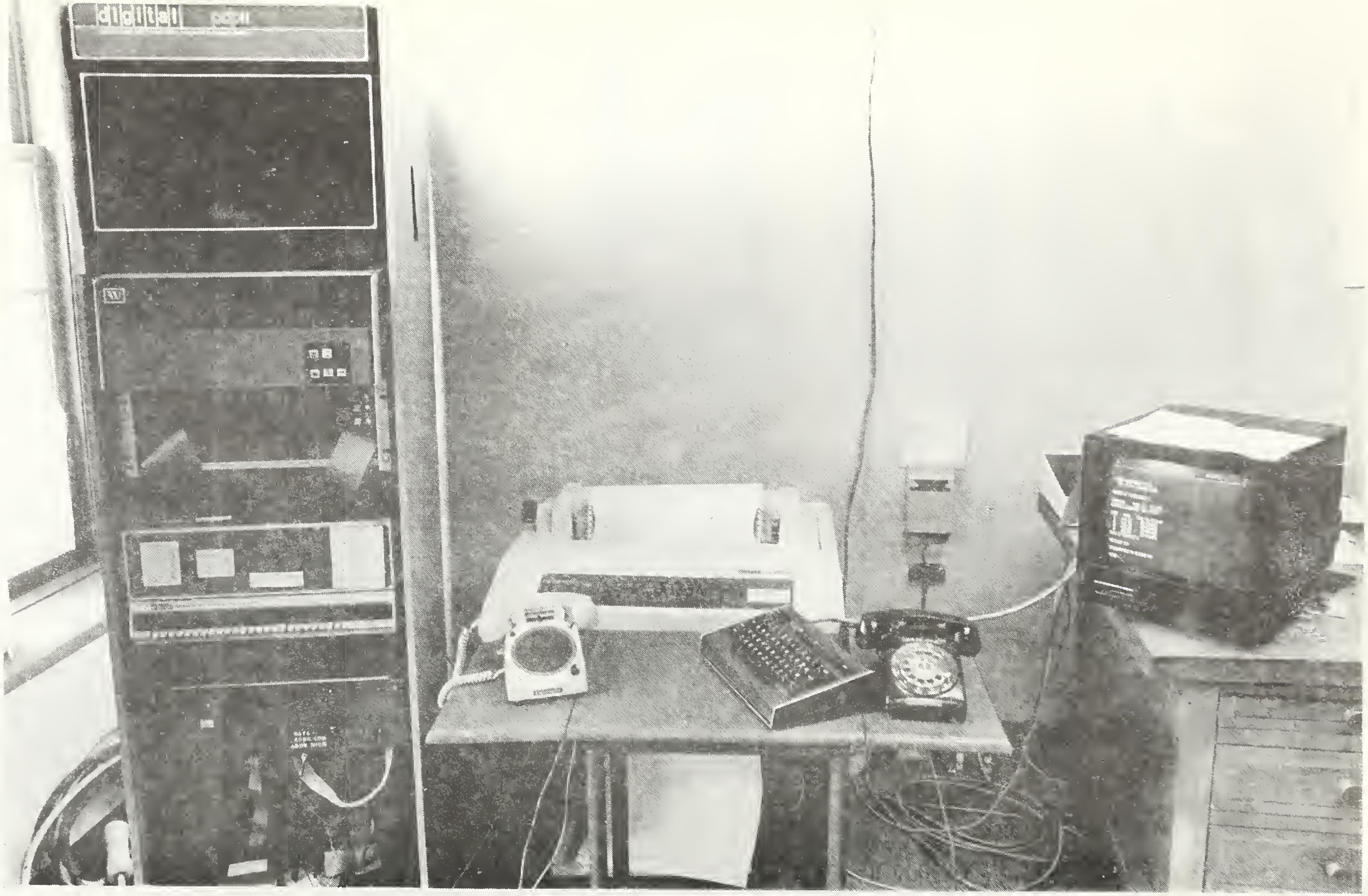


Figure 6.1
CENTRAL COMPUTER SYSTEM AND PERIPHERALS

The telephone communication link to Carnegie-Mellon University utilizes standard asynchoronous line interfaces and modems. The link currently permits communication with remote computers at 1200 baud (120 characters per second) and communications programs have been developed for using other computer systems as back-up systems.

6.3 Interface Console

The microprocessor-based Interface Console is housed in the same cabinet as the Central Computer System at the Control Center. It consists of an 8080 microprocessor, a bidirectional modem, and an auxiliary keyboard, and is connected to a high power VHF FM radio transceiver through a telephone line. The microprocessor provides the key link between the Central Computer System and the Control Center radio transceiver and transmits trip data from the Central Computer System. The bidirectional modem converts trip data into standard U.S. data transmission tones, and receives and decodes acknowledgment signals from the vehicle. An auxiliary keyboard is also provided to permit transmissions to vehicles independent from the Central Computer System; thus communications can be maintained even if the Central Computer System has malfunctioned. The Interface Console is shown in Figure 6.2.

After a fare and estimated trip time are computed and the dispatcher has assigned a vehicle to the trip, the fare, time, and vehicle number are transferred to the Interface Console using 12 parallel I/O lines. The low order eight bits of each twelve bit word constitute the actual data to be transmitted to a vehicle, while the high order four bits are used as a word counter. For each word transfer, the low order bits are loaded and the word counter is incremented. The signals must remain stable for approximately 300 micro-seconds while the information is transferred into a holding buffer; all data transfers are made from the Central Computer System to the holding buffer prior to initiating any radio transmissions.

After all information has been transferred to the buffer, the word counter is reset to zero, microprocessor priorities are reset, and the vehicle transmission process is initiated. First, the transmit line is keyed for approximately 1/2 second to permit the carrier detect circuit to lock onto the 2225 Hz tone. Next, data words are transmitted serially at 120 baud until the entire buffer has been sent. Approximately 1/4 second after the last data word has been sent the transmitter is released. If the RSVP meter has received the data with no errors, the vehicle number is returned as a positive acknowledgement that no errors occurred. If the microprocessor does not receive such an acknowledgement within a specified period of time, the entire transmission sequence is repeated automatically (up to three times). In any case, the Central Computer System is interrupted and informed of the success or failure of the transmission. This method assures that only completely correct messages are accepted in the face of often severe transmission difficulties. If three repetitions occur with no acknowledgement, the Operator may either relay the information verbally or wait until the vehicle has moved to a location that is not subject to radio interference. Since radio transmissions occur at 120 bits per second, all transactions may be concluded in less than two seconds.

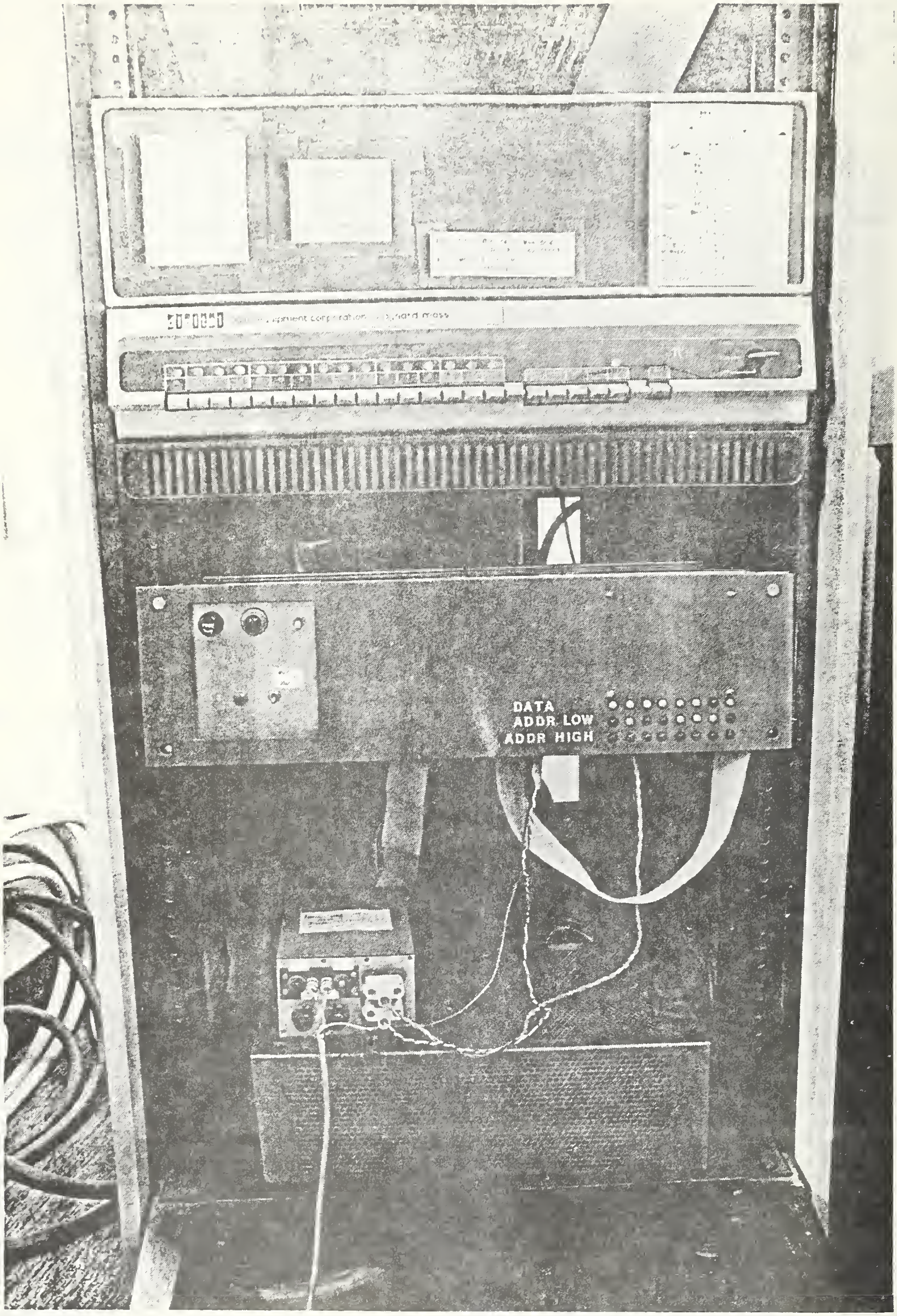


Figure 6.2
INTERFACE CONSOLE

6.4 Vehicle Communications

RSVP System communications adhere to the U.S. standard for low speed FSK modulation. The answer frequencies (2025 Hz space, 2225 Hz mark) are used for transmission from the Control Center to vehicles, and the originate frequencies (1070 Hz space, 1270 mark) are used for transmissions from vehicles to the Control Center. Although current transmissions occur at 120 bps, it is anticipated that this rate will be increased as more testing is undertaken. The maximum data transfer rate using this scheme is 600 bps.

The transmission format is shown in Figure 6.3. Two four-bit nibbles determine the eight bit word to be sent. These nibbles may contain display number and display data, two digits of address, or a code word. (See Section 7.2). Figure 6.4 indicates the data stream to the modem which in turn converts the mark and space levels to the appropriate frequency.

The actual base station transceiver is linked to the RSVP Control Center with an exclusive use telephone line. The telephone line interface unit has been modified to accept digital keying and the FSK modulation, which is entered through the microphone input. The interface unit keys and modulates the main transceiver as well as receiving at the operations center any vehicle messages.

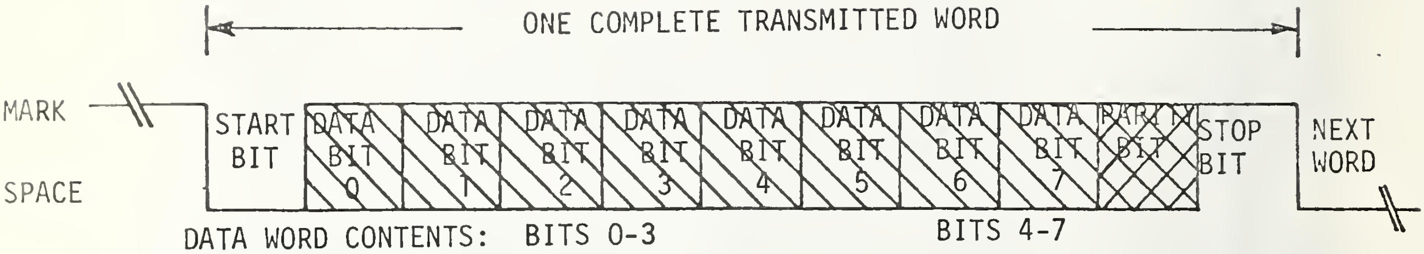
Peoples Cab Company has obtained from the FCC a 75 watt station license for digital communication on channel 5 1/2 (152.405 and 157.665 MHz), with the provision that channel sensing on channels 5 and 6 prevents interference from the digital signal. This license provides expanded radio coverage and permits the RSVP System to serve all of Allegheny County.

6.5 Operating Procedures

The RSVP System currently is capable of calculating and displaying fare and estimated trip time for four types of service including standard exclusive ride taxi service, prior to actually taking the trip. The request-response-delivery process is initiated either by a telephone call from a potential customer or by a radio message from a driver, and is terminated either by the completion of a trip or by a customer's decision, after being informed of the fare and estimated trip time, not to use the service. (Refer to Figure 6.5).

In the case of a telephone request, the operator obtains trip data (i.e. origin address, destination address, and number of passengers) from a dialogue with the caller and enters the data via the Operations Console keyboard. If the address data are valid (i.e. both addresses exist in the Address-Coordinate File) the fare and estimated trip time are calculated and displayed. After communicating the information to the customer, if service is desired the operator then enters the type of service requested, specifies a vehicle and initiates transmission of trip data to the assigned vehicle. The fare and estimated time are displayed in the vehicle.

To process a radio request, the operator obtains initial trip data from a dialogue with the driver; after the fare and estimated trip time are calculated they are transmitted to the vehicle and displayed to the customer.



DATA WORD CONTENTS:	BITS 0-3	BITS 4-7
DISPLAY WORD-	DISPLAY NUMBER	DISPLAY DATA
ADDRESS WORD-	2'ND SIGNIFICANT DIGIT 4'TH SIGNIFICANT DIGIT	1'ST SIGNIFICANT DIGIT 3'RD SIGNIFICANT DIGIT

Figure 6.3

DATA TRANSMISSION FORMAT

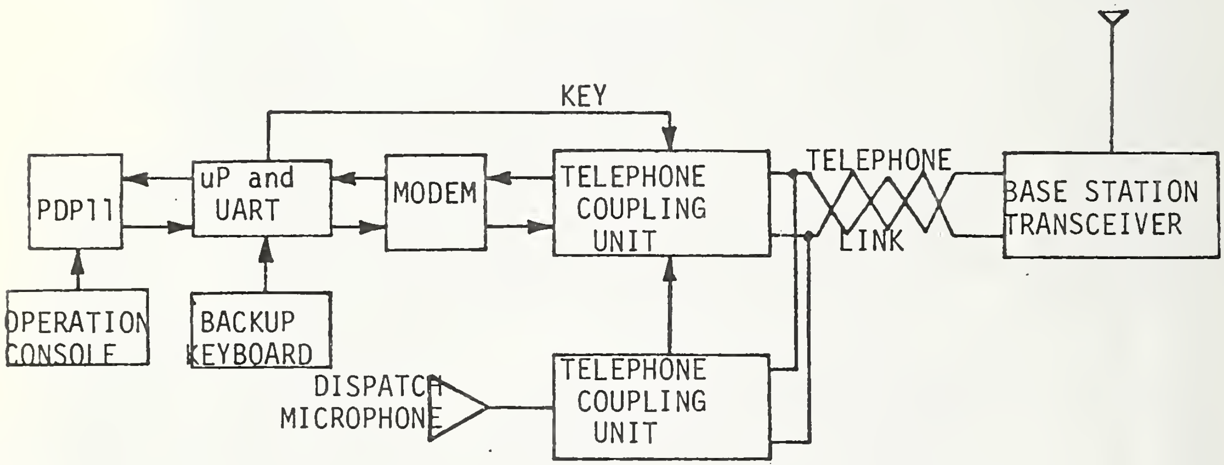


Figure 6.4

BASE STATION CONFIGURATION

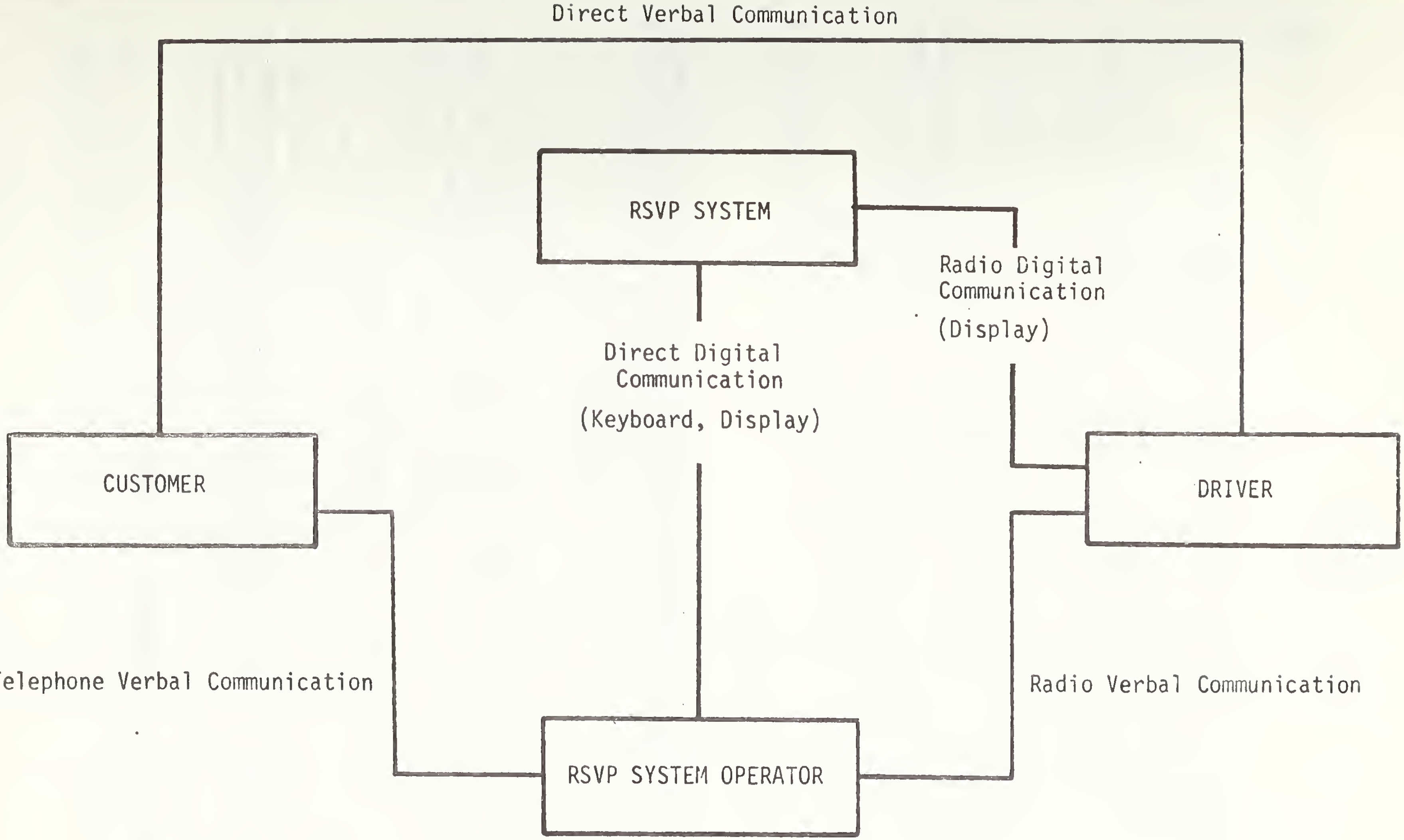


Figure 6.5

FLOW PATHS OF DATA AND MODES OF INTERACTION

7. VEHICLE HARDWARE

7.1 Overview

The RSVP System vehicle hardware package consists of a commercially available VHF FM radio transceiver and a custom-built RSVP meter. The radio transceiver and the RSVP meter are connected by a single cable. The RSVP meter contains a communication interface, a numeric display and metering circuitry. These components are packaged in a compact aluminum enclosure with a locking mechanism. The frequencies used for vehicle communications conform to U.S. standards for low speed FSK modulation, and the RSVP System operates on an exclusive voice and data radio channel. The communication interface of the RSVP meter performs parity error checking and sends an acknowledgment to the Control Center Interface Console, indicating whether or not transmissions have been received correctly. A numeric display shows the trip fare and estimated trip time generated by the Central Computer, or the fare determined by the electronic meter in the event of a computer failure. The metering circuitry for back-up fare calculation essentially simulates the conventional taxi meter. A Hall-effect sensor mounted on the transmission generates pulses proportional to distance travelled, and an internal oscillator generates timing pulses both for metering and for communication synchronization.

7.2 Conventional Taxi Meter Mechanisms

In order to develop the hardware for RSVP System back-up fare calculations, it is necessary to understand the functions of conventional taxi meters. In general, the fixed portion of the fare in conventional metered taxicabs is the initial cover charge for the flag drop. The variable portion, which is accumulated over the length of the ride, is determined by the number of revolutions of the main drive mechanism of the meter. The rotation of the main drive is governed by the rotation of two other drives, one connected to the speedometer and the other to a clock. At a given instant, the faster of the two drives causes the main drive to rotate while the other slips. The speedometer drive, denoted by S_d, can rotate the main drive S by a complete revolution for every δ miles traveled; the clock drive S_p can do likewise for every τ minutes lapsed. When S completes a revolution, the meter trips and the meter fare is incremented by a known amount C. Typical values for $\delta = \tau$ and C are $\delta = 1/6$ mile, $\tau = 1$ minute and C = 10 cents.

The equation of motion of S can be expressed in terms of the instantaneous velocity v(t) of the vehicle. Let x(t) denote the position of the vehicle at time t. The number of revolutions of the drives S, S_d and S_p are represented by g(t), $g_d(t)$, and $g_p(t)$, respectively. Suppose that during the interval (t, t + dt) the vehicle moves a distance dx. Then

$$g_d\,(t + dt) - g_d(t) = \frac{dx}{\delta} = \frac{v(t)\;dt}{\delta} \tag{7.1 a}$$

$$g_p\,(t + dt) - g_p\,(t) = \frac{dt}{\tau} \tag{7.1 b}$$

and the derivatives of g_d and g_p are respectively

$$\dot{g}_d = v(t)/\delta \tag{7.2 a}$$

$$\dot{g}_p = 1/\tau \tag{7.2 b}$$

The equation of motion of S can be written as

$$\dot{g} = \max\,\{\dot{g}_d,\ \dot{g}_p\}$$

$$\dot{g} = \max\,\{v(t),\ H\}/\delta \tag{7.3}$$

where $H = \delta/\tau$ and is called the threshold velocity. For a trip beginning at time $t = 0$ and ending at $t = T$.

$$g(T) = \frac{1}{\delta}\int_0^T \max\,\{v(t),\ H\}dt \tag{7.4}$$

Then, the variable portion of the fare is given by

$$F_c(T) = C\;\overline{g(T)} \tag{7.5}$$

where $\overline{g(T)}$ is the largest integer which is less than or equal to $g(T)$. The maximum error committed in imposing the integer restriction of Eq. (7.5) is C (e.g., 10 cents). Hence the variable portion of the fare can be approximated by

$$F_c(T) = \frac{C}{\delta}\int_0^T \max\,\{v(t),\ H\}\;dt \tag{7.6}$$

An example for Eq. (7.6) is given in Figure 7.1. It is seen that the area under the curve $\max\,\{v(t),\ H\}$ is the sum of two parts: X_m, the total distance traveled at velocity $v(t) \geq H$ and HT_k, where T_k is the total time lapsed at velocity $v(t) < H$. Hence Eq. (7.6) may be written in the equivalent form

$$F_c(T) = \frac{CX_m}{\delta} + \frac{CT_k}{\tau} \tag{7.7}$$

In the case of stop-and-go traffic, the instantaneous velocity is either zero or equal to the average running speed $V \geq H$, as shown in Figure 7.2. It can be shown by substitution into Eq. (7.7) that for stop-and-go traffic

$$F_c(T) = C\left[\frac{1}{\delta} - \frac{1}{V\tau}\right]X + \frac{CT}{\tau} \tag{7.8}$$

where $X = X_m = V(T - T_k)$ is the total trip distance. Eq. (7.8) is identical to the general formula used in exclusive ride taxi fare calculation for the RSVP System.

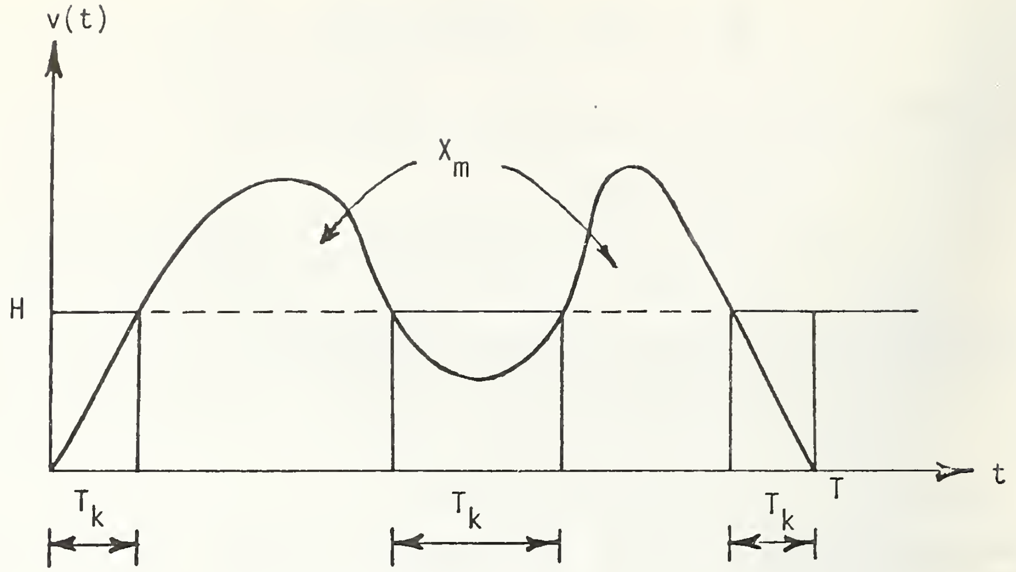


Figure 7.1
METERED TAXI FARES

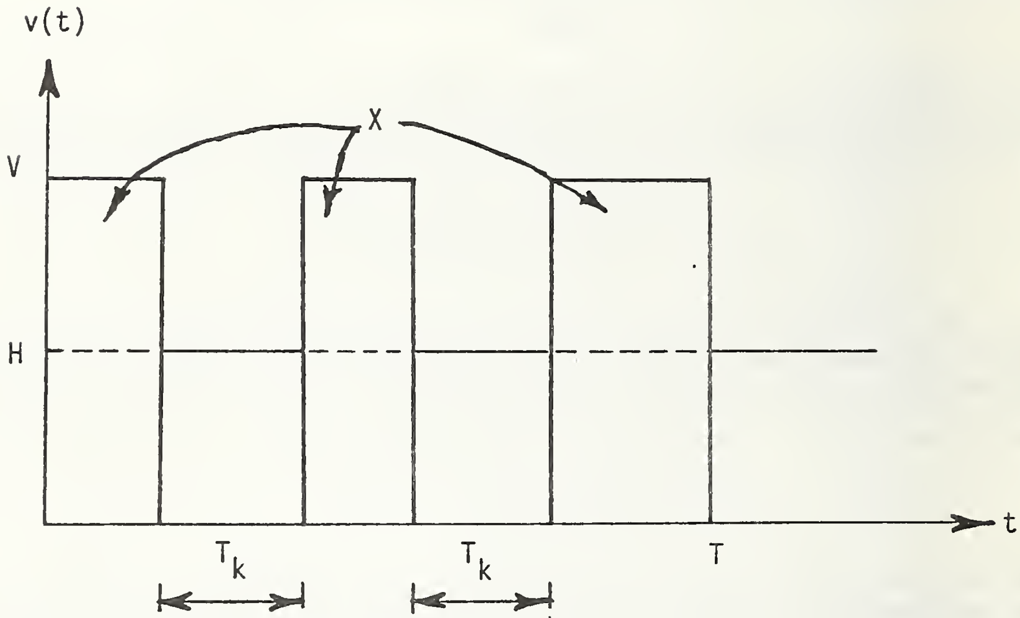


Figure 7.2
STOP-AND-GO TRAFFIC

The pricing mechanism of the conventional meter is understood more clearly by defining the distance rate as the time rate respectively as follows:

$$R_d = C/\delta \tag{7.9 a}$$

$$R_p = C/\tau \tag{7.9 b}$$

thus R_d represents the monetary value of a unit of travel distance while R_p represents that of a unit of travel time. The threshold velocity can be expressed directly as

$$H = R_p/R_d \tag{7.10}$$

Table 7.1 includes the threshold velocities for various distance and time rates. Using Eqs. (7.9) and (7.10), Eq. (7.6) becomes

$$\begin{aligned} F_c(T) &= \int_0^T \max\{R_d\, v(t),\, R_p\}\, dt \\ &= \int_0^T dF_c(t) \end{aligned} \tag{7.11}$$

where

$$dF_c(t) = \max\{R_d\, dx,\, R_p\}dt \tag{7.12}$$

is the infinitesimal fare increment at time t.

In the context of pricing, Eqs. (7.11) and (7.12) can be interpreted by viewing the distance rate R_d as the cost of providing transportation service per unit distance; and the time rate as the cost of renting (occupying) a vehicle per unit time. Thus, when the instantaneous velocity $v(t)$ is greater than the threshold velocity H, the taxicab is rendering transportation serivce for which the rider is charged at price R_d. On the other hand, if $v(t) < H$, no service is being provided and the rider is charged the rent R_p. The importance of the threshold velocity lies in the fact that it alone determines whether at a given instant during a trip the rider is being charged for the service on the basis of distance or time.

7.3 Back-up Fare Calculation

The backup fare calculation mechanism in the RSVP system reflects current practice in metered taxi fare calculations. In discrete form, Eqs. (7.11) and (7.12) can be expressed as

$$F_c(T) = \sum_{n=1}^{N} \Delta F_{cn} \tag{7.13}$$

TABLE 7.1

THRESHOLD VELOCITIES FOR VARIOUS DISTANCE AND TIME RATES

$1/R_p$ \ R_d	10	20	30	40	50	60	70	80	90	100	110	120
12	30	15	10	7.5	6	5	4.3	3.75	3.3	3	2.7	2.5
11	32.7	16.4	10.9	8.2	6.5	5.4	4.7	4.1	3.6	3.3	3	2.7
10	36	18	12	9.	7.2	6	5.1	4.5	4	3.6	3.3	3
9	40	20	13.3	10	8	6.7	5.7	5	4.4	4	3.6	3.3
8	45	22.5	15	11.25	9	7.5	6.4	5.6	5	4.5	4.1	3.75
7	51.4	25.7	17.1	12.9	10.3	8.6	7.3	6.4	5.7	5.1	4.7	4.3
6	60	30	20	15	12	10	8.6	7.5	6.7	6	5.4	5
5	72	36	24	18	14.4	12	10.3	9	8	7.2	6.5	6
4	90	45	30	22.5	18	15	12.8	11.25	10	9	8.2	7.5
3	120	60	40	30.	24	20	17.1	15	13.3	12	10.9	10
2	180	90	60	45	36	30	25.7	22.5	20	18	16.4	15
1	360	180	120	90	72	60	51.4	45	40	36	32.7	30

1. Threshold velocities are expressed in miles per hour.
2. R_d is given in cents per mile.
3. $1/R_p$ is given in seconds per cent (e.g. $1/R_p$ = 12 second per cent is the reciprocal of R_p = 60/12 = 5 cents per minute).

and

$$\Delta F_{cn} = \Delta F_c(n\Delta t) = \max\left\{R_d\ (\Delta_x)_n,\ R_p\Delta t\right\} \tag{7.14}$$

where Δt is the sampling period, $(\Delta x)_n$ is the distance traveled during the n^{th} sampling period and N is the number of samplings. The fare for a ride now becomes

$$F = F_o + \sum_{n=1}^{N} \Delta F_{cn} \tag{7.15}$$

where F_o is equal to the flag drop charge.

The block diagram for a hardware realization of Eqs. (7.13) and (7.14) is given in Figure 7.3. The output of the velocity sensor is a pulse train whose frequency G_d varies according to the instantaneous velocity of the vehicle. The time base generates a pulse train of fixed frequency G_p, while the sample clock provides the sampling signal. The purpose of the decision device in Fig. 7.3 is to determine whether the next fare increment is to be effected on the basis of distance or time. The pre-divide stages for distance and time (with divisors Q_d and Q_p respectively) convert the pulse trains from the velocity sensor and the time base to a common unit of pulses per one cent. The final divide stage (with divisor Q) converts distance or time pulses into a pulse train to increment the fare counter. Thus at each occurrence of a pulse at point E, the fare counter is incremented by W cents, where W is a preselected value (e.g., 10 cents).

In order to identify the design issues involved in the hardware realization of Figure 5.3, consider the two cases of slow motion and fast motion separately. For the case of slow motion with $v(t) < H$, points C and D are connected and the incremental fare is determined on the basis of travel time. Since the fare increases by W cents every time a pulse arrives at point E, and since the time rate is R_p, the period of the pulse train at point E must be W/R_p.

Hence

$$\frac{Q_p Q}{G_p} = \frac{W}{R_p}$$

or

$$\frac{G_p W}{Q_p Q R_p} = 1 \tag{7.16}$$

Similarly, considering the case of fast motion with $v(t) > H$, points B and D in Figure 7.4 are connected. Then the following equality must hold:

$$\frac{G_d W}{Q_d Q R_d} = 1 \tag{7.17}$$

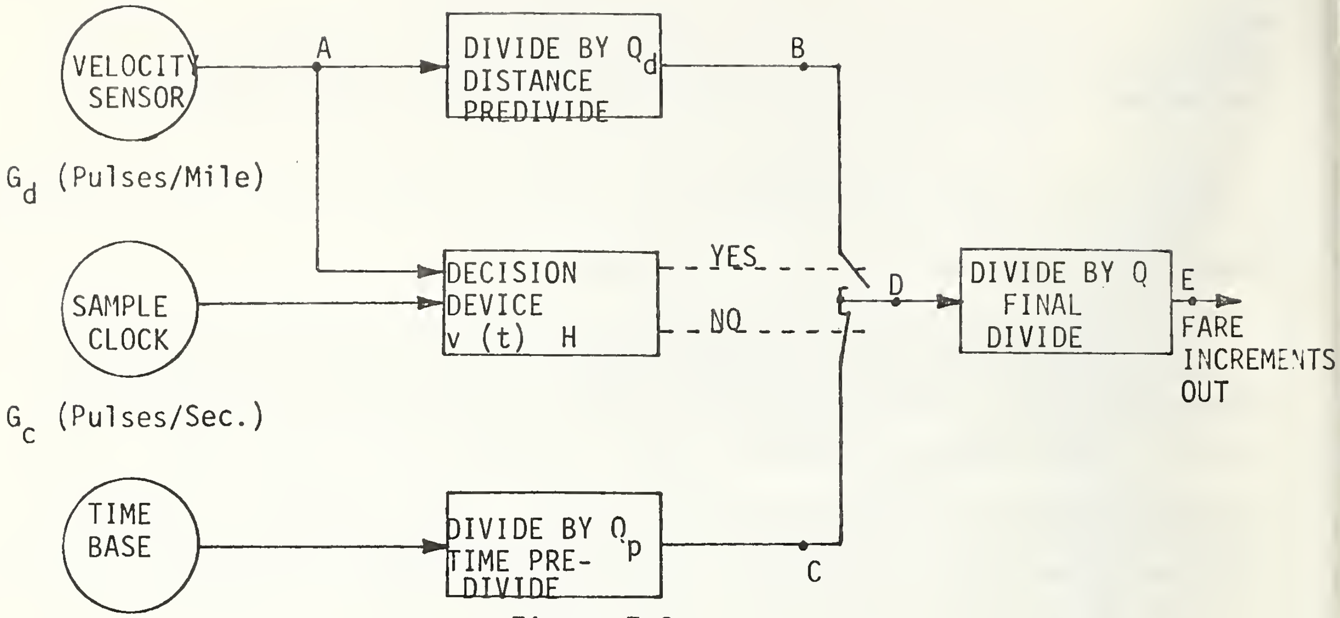


Figure 7.3

BLOCK DIAGRAM OF A TIME/DISTANCE METERING HARDWARE REALIZATION (LINEAR DIVIDE)

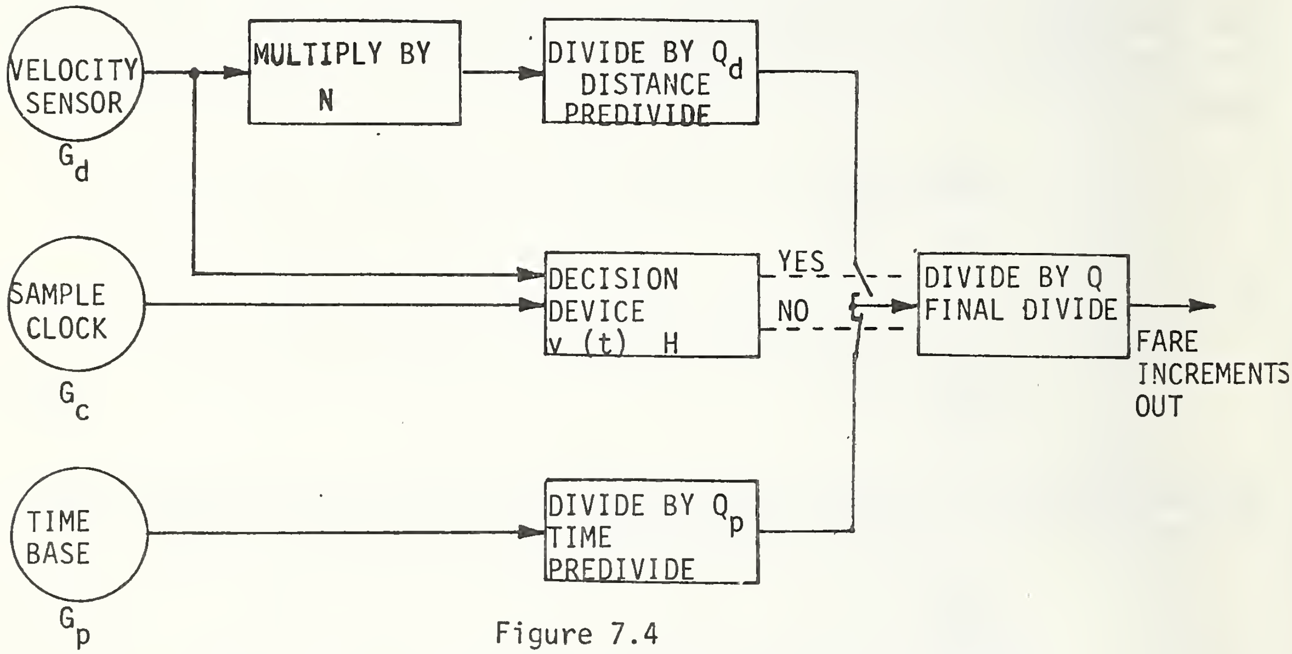


Figure 7.4

BLOCK DIAGRAM OF MULTIPLY/DIVIDE METERING MECHANISM

The result of equating Eqs. (7.16) and (7.17) is

$$\frac{G_d}{Q_d R_d} = \frac{G_p}{Q_p R_p} \tag{7.18}$$

As an example for Eqs. (7.16) through (7.18) consider the given values:

R_d = 10 cents/mile
R_p = 10 cents/minute
G_d = 4,000 pulses/mile
G_p = 1 pulse/second = 60 pulses/minute

substituting these values into Eq. (7.18), the ratio of Q_d/Q_p can be determined. Specifically, the values of Q_d = 200 and Q_p = 3 are found to satisfy that equation. Suppose now that the fare is to be incremented in W = 1 cent units. Then from Eq. (7.16) or (7.17), Q = 2. If W = 10 cents, Q = 20.

An important consideration in the design of the back-up fare calculation, has been the flexibility to implement any distance and time rate combination. In the preceding example, the given values imply an unrealistically high value of H = 60 mph for the threshold velocity. Using a computer-generated table of division ratios vs. distance rate and time rate, it was discovered that for some values of R_d, R_p, G_d and G_p there are no integral solutions to Eqs. (7.16 through 7.18). An implementation based on rounding the non-integer solutions to the nearest integers would involve errors in fare calculation analogous to round-off error commonly encountered in floating-point computation.

The desired flexibility has been achieved in the present implementation. by using an extra multiply stage before the distance pre-divide stage, as shown in the block diagram of Figure 7.5. Then, Eq. (7.18) becomes

$$\frac{NG_d}{Q_d R_d} = \frac{G_p}{Q_p R_p} \tag{7.19}$$

The extra factor can be manipulated to obtain integral solutions to Eq. (7.19). For instance, with

R_d = 70 cents/mile
R_p = 10 cents/minute
G_d = 4,000 pulses/mile
G_p = 1 pulse/second = 60 pulses/minute

Eq. (7.19) yields

$$\frac{400\ N}{7Q_d} = \frac{6}{Q_p}$$

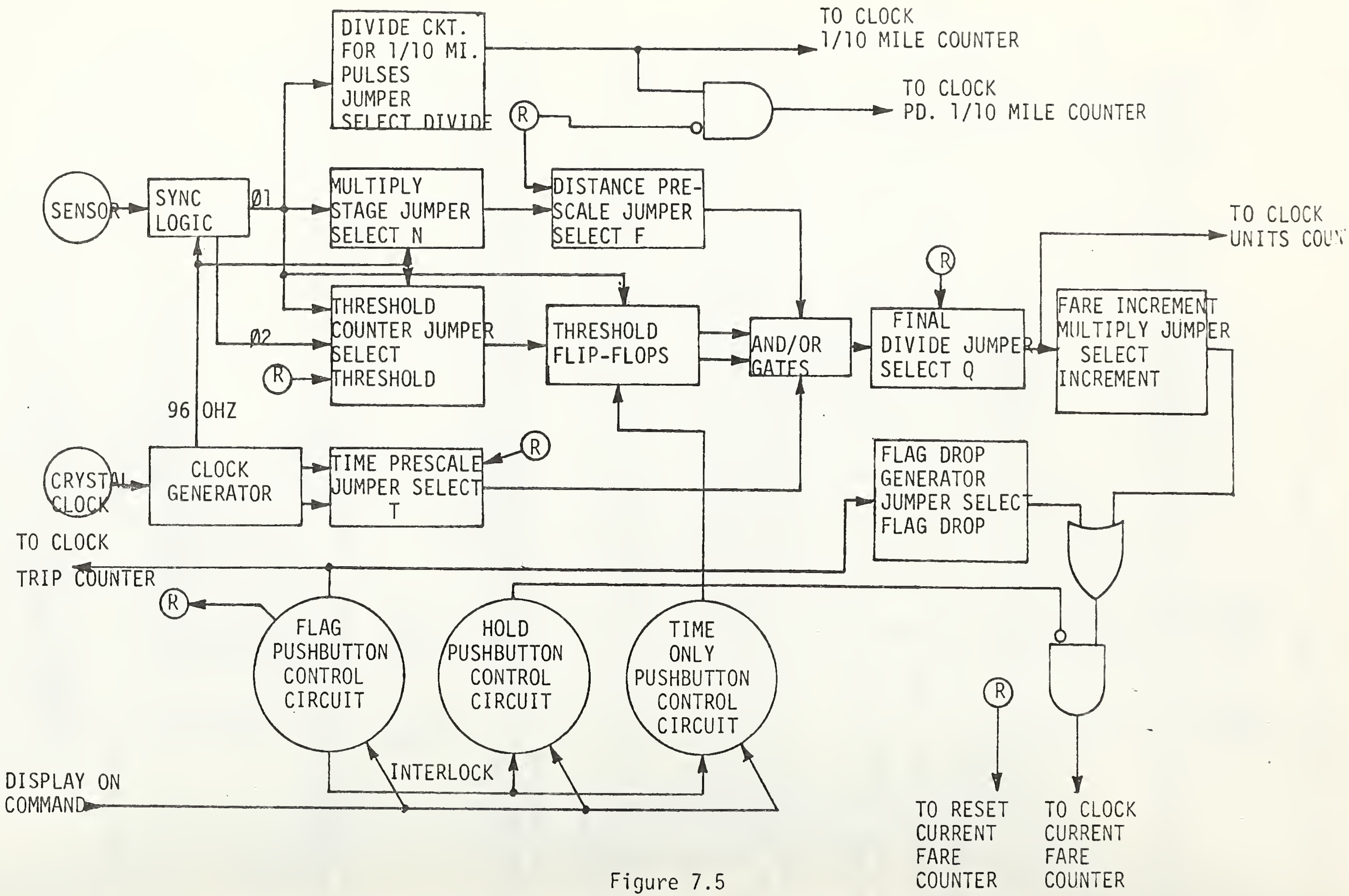


Figure 7.5

DETAILED BLOCK DIAGRAM FOR BACKUP METERING IMPLEMENTATION

which is satisfied by N = 7, Q_d = 200 and Q_p = 3. Using Eq. (7.16), Q = 2 is obtained for W = 1 cent. The advantages of the method depicted in Figure 5-4 are elimination of round-off error, flexibility and ease of implementation.

Figure 7.6 shows the hardware implementation for the RSVP back-up metering. The sensor input pulse G_d is synchronized to a high speed sample clock (in 960 Hz) and converted to a two phase signal. Phase ϕ_1 is used to clear the threshold counter and as count signal input for the distance multiply/divide stages. Phase ϕ_2 starts the threshold counter running at the sample clock frequency. If a pre-determined count (selected by jumpers) is reached, the threshold flip-flop is set to the distance position; otherwise it remains in the time position. The threshold F.F. simply determines which signal (i.e., time or distance) is used as the clocking signal for the final divide stage. Phase ϕ_1 is also used to clock a divide stage that yields 1/10 mile pulses. For example, if G_d is 4,000 pulses per mile, the divisor should be 400 to obtain 1 pulse per 1/10 mile. This signal increments a 1/10 mile counter and in conjunction with the flag status is used to increment a paid 1/10 mile counter.

The multiply stage in the distance path multiplies ϕ_1 by N, which is also jumper selectable. The output to the distance pre-scaler is a set of N pulses (in 960 Hz) for each pulse of the sensor. The distance pre-scaler divides this pulse train by Q_d according to Eq. (7.17).

The time clock signal G_p is crystal controlled and nominally pulses 15 times per second. The time pre-scaler divides the clock frequency by Q_p and the result goes to AND/OR gates, which are used to decide whether time or distance increments the final divide counter. Final divide stage scales the incoming pulse train by Q to yield fare increments. The fare increment multiply circuit determines the number of cents per fare increment and drives the current fare counter.

The flag drop generator determines the initial charge upon flag drop and is jumper selectable from 1 cent to 2.55 dollars. The flag drop pushbutton releases the meter reset function, displays the flag drop charge and increments the trip counter. The hold pushbutton holds the final divide circuit and cannot be reset. The time only pushbutton holds the threshold flip-flop in the time position and can be reset. Neither hold nor time only can be activitated without the flag being dropped.

7.4 Vehicle Hardware Configuration

The RSVP System utilizes vehicle hardware consisting of a commercially available VHF FM transceiver connected to a custom built RSVP meter. Since the RSVP meter contains all necessary circuits for communication interface, the radio transceiver requires no internal modification. The frequencies used for vehicle communications conform to U.S. standards for low speed FSK modulation, and the RSVP System operates on an exclusive voice and data radio channel.

The RSVP meter contains three major components which are packaged in a compact aluminum enclosure with a locking mechanism:

(a) A communication interface which includes all circuits for the radio-meter interface.

(b) A numeric display which allows 4 digits of fare information, 2 digits of estimated trip time, and 1 digit for seat or passenger identification;

(c) Metering circuitry which provides back-up fare calculation capabilities in the event of a computer failure.

Four threaded rods mount a printed circuit board stack onto the meter faceplate. Individual circuit cards are two sided G-10 boards that plug into the circuit board stack; the faceplate assembly then connects to the meter enclosure using a keylock switch that drives a sliding bar lock. This plug-in feature permits easy maintenance of the RSVP circuitry simply by removing the faceplate assembly and the stack. Table 7.2 describes the five circuit cards for the RSVP meter. Note that Card 305 (Microprocessor) is functionally identical to Card 304 (Metering) and will carry out the back-up fare calculation of the metering circuit.

Figure 7.6 shows the complete RSVP vehicle hardware which includes the antenna, the speedometer sensor, the radio transceiver and the RSVP meter. The antenna and the radio transceiver are essential components for communications. The RSVP meter circuit board stack can be removed from the case for servicing while the meter case (behind the circuit board stack in the figure) would be attached permanently to the vehicle. The speedometer sensor (in the foreground of the figure) would normally be mounted in the transmission. Note that only four cables are required: the antenna cable, the power cable for the radio transceiver, the speedometer sensor cable and the RSVP meter cable. All four cables terminate at the back of the radio transceiver. Figure 7.7 shows the radio transceiver and the RSVP meter in a taxicab. The RSVP meter is installed on top of a conventional electro-mechanical taxi meter for fare comparison. The extra wiring (in the right-hand corner of the figure) belongs to the electro-mechanical taxi meter and the dome light.

Figure 7.8 is the top view of the circuit board stack in the RSVP meter which is lying face down with the meter box removed. The circuit boards from bottom up are display, communication, interconnection and metering. The three connectors that plug various circuit cards together are shown in the center of the figure. (One short connector is located underneath the longer one.) The address switches on the second circuit board from the bottom (at center right of the figure) define the unit number. This unit has been set to respond to unit No. B181 in hexa-decimal characters. Mounted onto the faceplate is the sliding bar lock, the curved end of which would normally be connected to a slotted lock wheel. (The wheel had been dismounted before the photograph was taken to provide a clearer view.) The shaft that actuates the multi-position switch used for meter readout can also be seen (in the lower left-hand of the figure). Figure 7.9 is the bottom view of the circuit board stack in the RSVP meter. The input Molex connector (at the top right-hand corner of the figure) supplies power as well as all radio connections to the meter. The switches (along the top) select various meter parameters, i.e., flag drop charge, time rate, distance rate, etc. The back of pushbuttons for flag, hold and time can also be seen (at the lower right-hand corner in the figure).

Table 7.2

CIRCUIT CARDS FOR THE RSVP METER

Card Number	Size	Description and Functions
Display Board 301 C	2 3/4" by 6"	Seven digit display with drivers; Scan oscillator; Power fail circuit.
Communications Board 302 B	2 3/4" by 8 1/2"	Pushbuttons and latches; Main oscillator for carrier detect Modem, UART, addressing circuits audio circuit, address switches, display decoder.
Interface 303 D	2 3/4" by 8 1/2"	Buffers, card interconnections, power routing, radio control circuit, memories
Metering 304 A	2 3/4" by 8 1/2"	Metering circuit, keylock switch, fare jumpers, plug to meter housing.
Microprocessor 305 A	2 3/4" by 8 1/2"	Microprocessor, memories.

Figure 7.6
COMPLETE RSVP VEHICLE HARDWARE

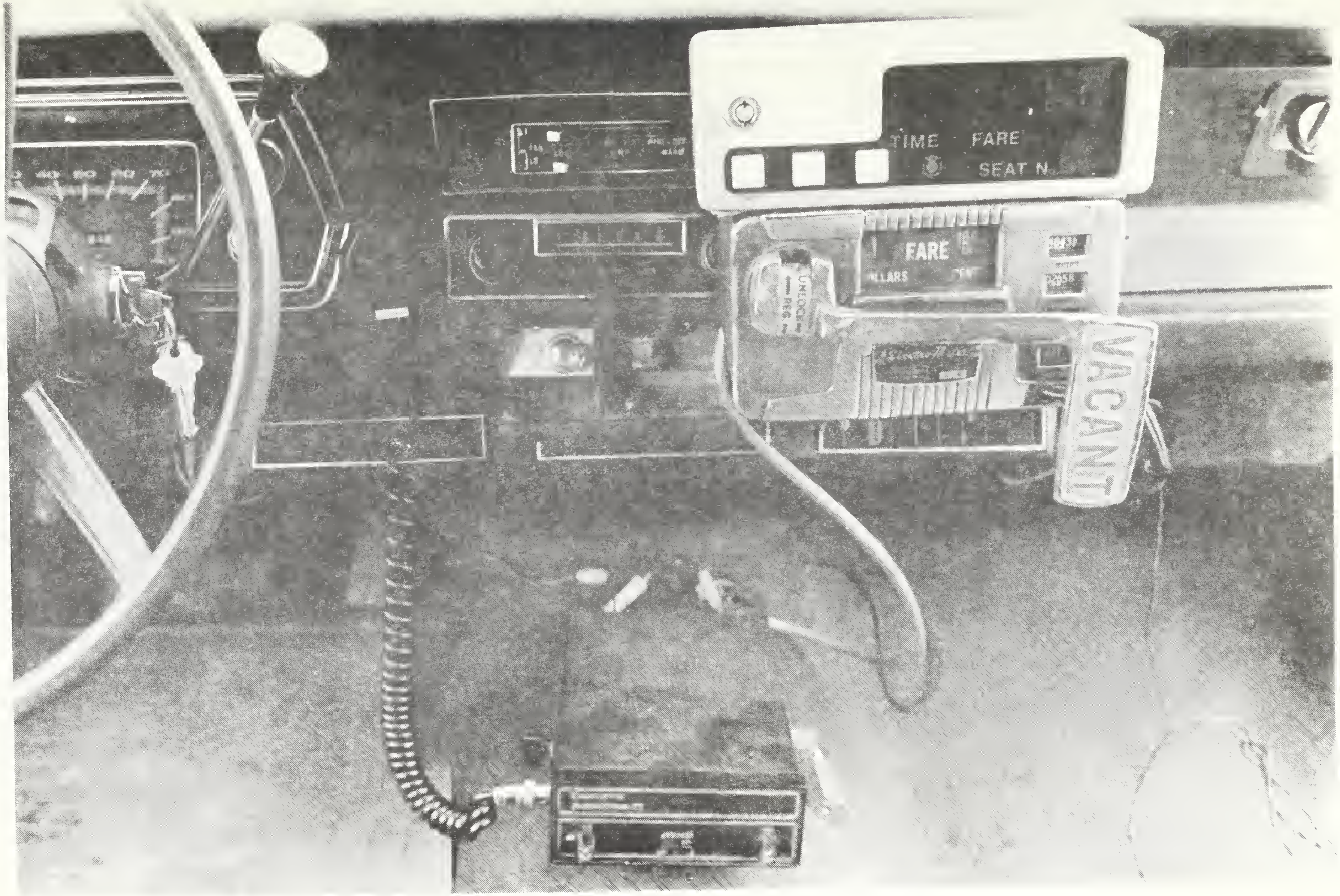


Figure 7.7
RADIO TRANSCEIVER AND RSVP METER IN A TAXICAB

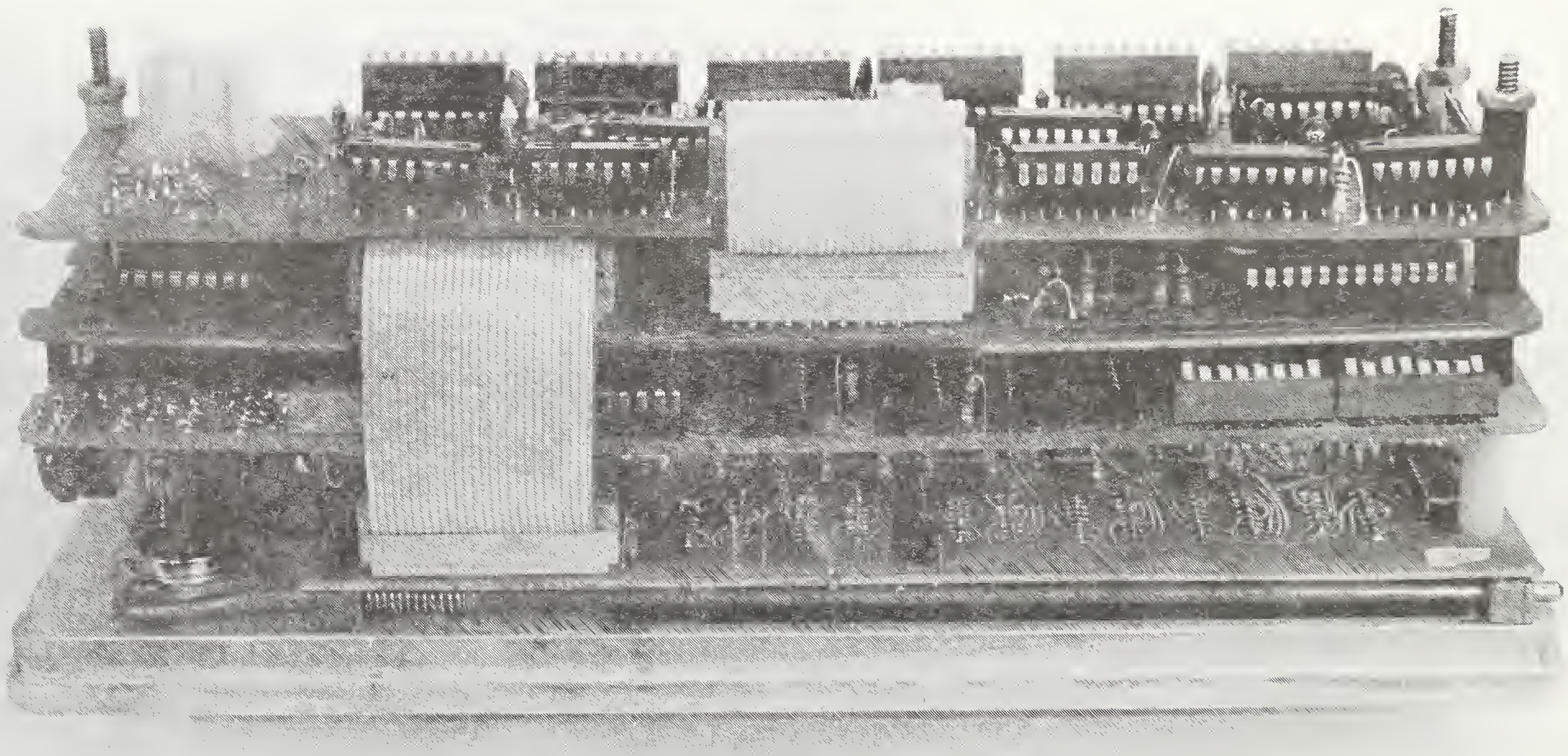


Figure 7.8
TOP VIEW OF CIRCUIT BOARD STACK IN RSVP METER

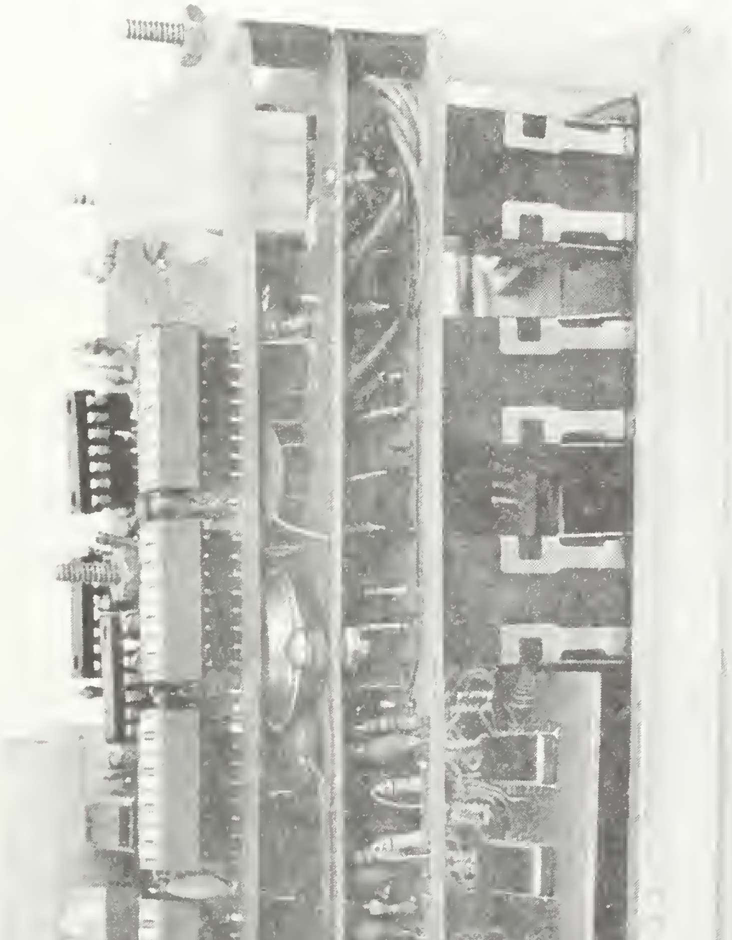


Figure 7.9
BOTTOM VIEW OF CIRCUIT BOARD STACK IN RSVP METER

7.5 Communication Interface

At the RSVP Control Center, the fare data calculated by the Central Computer System are transmitted by the microprocessor-based (8080) Interface Console. The communication interface of the RSVP meter in the vehicle can receive up to seven digits of information. A block diagram of the communication interface circuitry is shown in Figure 7.10. The communication interface of the RSVP meter performs parity error checking and sends a positive acknowledgment to the Control Center Interface Console, indicating whether or not transmissions have been received correctly. Microprocessor technology has been incorporated into the RSVP System via the Interface Console which serves as a communications front-end for the PDP-11 by buffering information to be transmitted to vehicles, initiating actual transmissions, and determining whether any parity errors occurred. An auxiliary keyboard will permit transmissions to vehicles independent from the Central Computer System, thus communications can occur even if the Central Computer System has malfunctioned.

The communication interface operates from 5 volts DC and is specifically designed to use a single supply source. The audio signal from the radio is fed through a bandpass filter (Point A in Figure 7.10) and applied to the carrier detect circuit and comparator. The comparator produces 50% duty cycle square waves which change at the zero intersection of applied sine wave signals. A single-chip modem detects both modulator tones from the comparator and outputs the resulting data stream to a UART chip (Point B in Figure 7.10).

Upon receiving a carrier tone, the carrier detect circuit enables the UART and addressing circuits. A 0.5 second delay occurs before and after the carrier detect signal to prevent voice transmissions from activating the display unit. After the carrier has been received for a sufficient time, the UART acts as a serial-to-parallel data converter, controlled by the master clock (Point C on Figure 7.10). If the received word has no parity or framing errors, it is compared to the first address word; if it matches, the address selector is advanced and the second word is likewise compared. If the address received is a valid vehicle address, a flag is set and the display bus enabled in the appropriate vehicle. Subsequent words are then loaded into the display or decoded as control characters.

A typical vehicle message consists of two address characters, a character containing the "display on" code, six or seven display characters, and a character containing the "end-of-text" code. Each character is formed using 8 bits. The "display on" code initializes the meter and turns on indicator lights and pushbutton lights in the meter. The "end-of-text" code signals that a message is complete and causes the positive acknowledgement sequence to be initiated.

First, the transmit latch is activated and the transmitter is keyed. After a 0.5 second delay, vehicle address words are sent from the address select switches to the modem and then into the transmitter as audio tones. After another 0.5 second delay, the transmitter is unkeyed. Note that this process provides a straight-forward way to determine whether a vehicle is within receiving range, simply by addressing it and monitoring the answer-back signal.

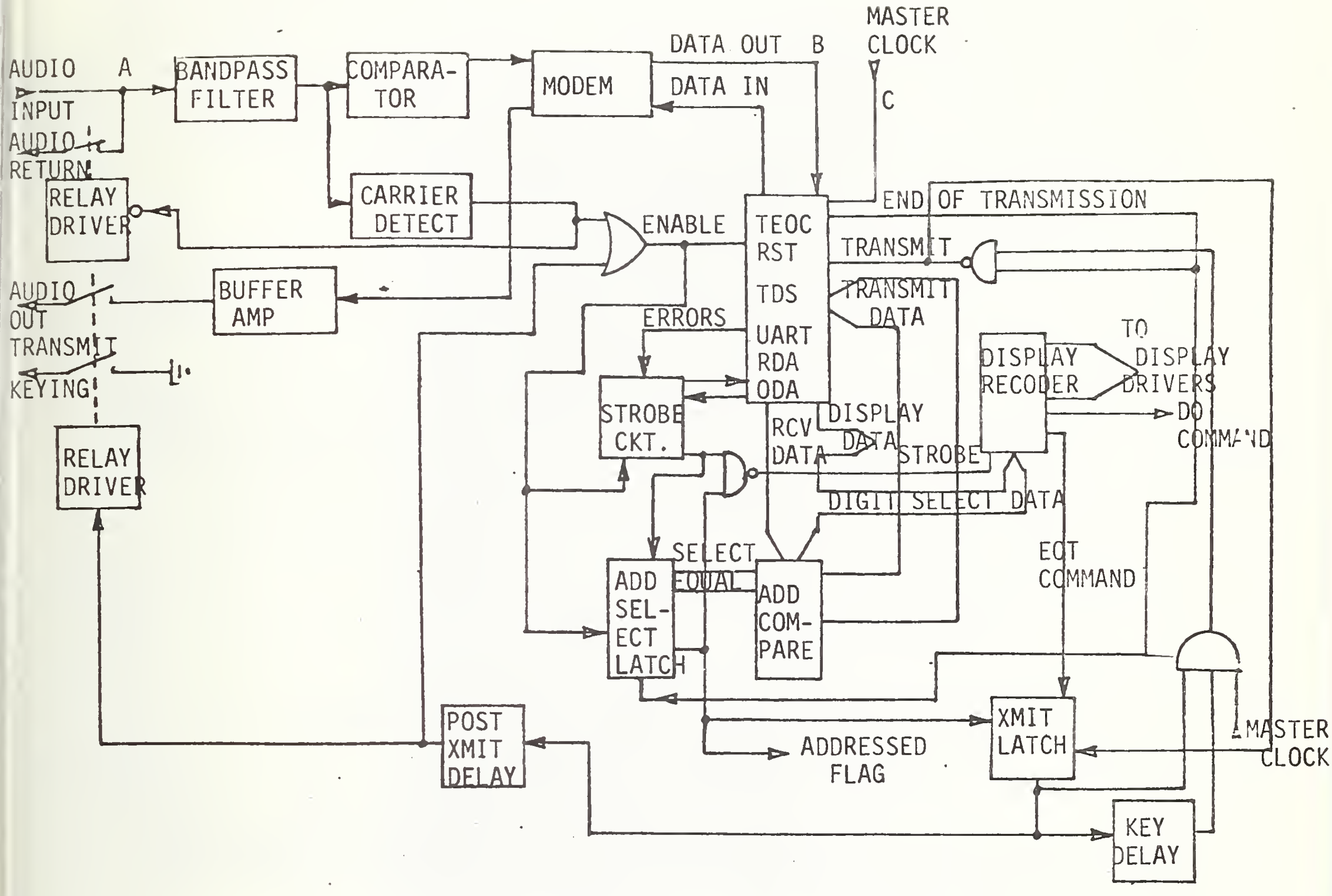


Figure 7.10

BLOCK DIAGRAM OF COMMUNICATION CIRCUITRY

7.6 Numeric Display

RSVP System status indicators consist of a seven-digit numeric display and three illuminated pushbuttons for flag drop, time-only metering, and hold. The incandescant numeric display consists of 4 digits of fare information (up to $99.99), 2 digits of estimated trip time (in minutes), and 1 digit for seat or passenger number. RSVP mode operation is indicated by having all three pushbuttons lit simultaneously. The digit displays are not monochromatic and are connected to latch-decoder-drivers which provide storage capabilities. Thus the digits are visible, even in bright light, until they are turned off or unless a power failure occurs.

Figure 7.11 shows the front face display of RSVP meter. The trip information on display in this case indicates that, in the RSVP mode, the strip would cost $8.30 with an estimated time of 15 minutes for passenger No. 3. Note the clarity and contrast of the incondescant numeric display. The meter readout keylock can also be seen (in the upper left-hand corner of the figure).

In normal meter mode only, the fare counter is selected and the current fare is output to the display. For summary information, a keylock switch selects the counter to be displayed. This switch has seven active positions:

(1) In service (permits either meter or RSVP display operations);

(2) Display units (number of fare increments);

(3) Display trips;

(4) Display total miles;

(5) Display paid miles;

(6) Power fail reset (resets power fail indicator light);

(7) Reset (clears all counters).

In RSVP mode, the fare counter is disabled and a tri-state buffer from the communications circuitry gains control of the display bus and displays the fare transmitted from the computer. Computer communications have priority and can override metering functions.

7.7 Metering Circuitry

Counting and multiplying circuits in the RSVP Moter are implemented using type 2240 bipolar programmable counters; the remaining circuitry utilizes CMOS technology. A Hall-effect sensor mounted on the transmission housing generates 4 pulses per revolution and thus is capable of measuring distances with a precision of 1.5 feet. A 15.360 kHz oscillator which maintains an accuracy of 0.001% over its temperature range provides timing pulses both for metering and for communications.

The metering circuitry functions as a back-up element of the RSVP System and as a source of actual time, distance, and revenue data for updating RSVP System files. Inputs to the metering circuitry are in the form of time pulses from the clock, distance pulses from the transmission sensor, a pulse from the flag button, a pulse from the hold button, a pulse from the time-only button, and two clocking signals. Outputs from the metering circuit are current fare pulses (1 cent per pulse), number of 1/10 miles travelled (1/10 mile per pulse), paid 1/10 miles travelled (1/10 miles per pulse), number of fare increments (1 unit per pulse) and number of trips (1 trip per pulse). The current fare applies only to the current trip being taken. However, the other quantities

Figure 7.11
FRONT FACE DISPLAY OF RSVP METER

are accumulated in five decade CMOS counters with a separate power supply and battery back-up as shown in Figure 7.12; thus the accumulated totals are accessible virtually indefinitely. The outputs of all counters are tri-state and are fed into a display data bus and a display didit select bus.

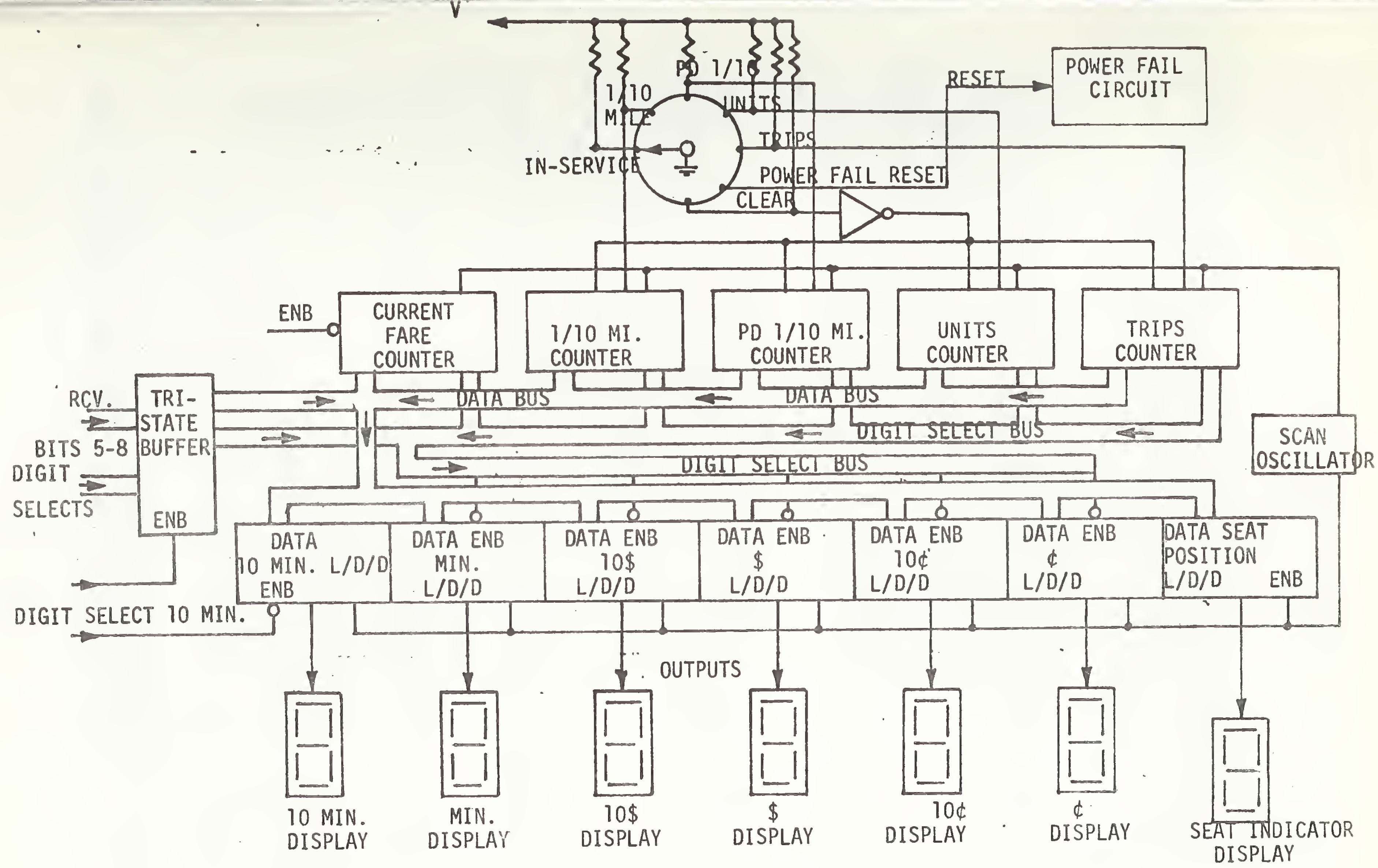


Figure 7.12

METERING CIRCUITRY

8. EXPERIMENTAL OPERATIONS

8.1 Overview

A number of operational issues that have inhibited the growth of standard taxi services primarily arise from the lack of adequate controls over cash transactions that occur in vehicles. In general, a fare calculation and collection system should compute fares precisely according to a filed tariff (i.e., be completely driver independent) and should record basic information about every trip.

Prior to undertaking experimental operations, a variety of shared ride services were planned. However, until 1974 taxi group riding was prohibited in Pennsylvania except in very limited circumstances. Due to the energy crisis in 1974, the Public Utility Commission issued an order that somewhat eased restrictions on group riding, although the associated fare calculation procedure was cumbersome and inequitable. Peoples Cab Company then used this PUC order as precedent and proposed a tariff which modified the Commission's fare calculation procedure by introducing the RSVP System, and which also further relaxed restrictions on group riding. After the tariff became effective 1 July 1976, the Company began gradually implementing a number of shared ride services.

Specific provisions of the Peoples Cab Company tariff define Group Taxicab Service as non-exclusive, door-to-door call or demand service in which persons having different origins and destinations share a vehicle. Since such ride sharing inevitably involves route deviations, each individual's fare is first computed as though the trip would be an exclusive taxi trip. Thus, in terms of time and distance used to compute fares, there is no penalty imposed on a customer due to route deviations. After the basic point-to-point fare is computed, it is discounted depending upon the degree of advanced notification given to the Company by the customer. In addition, the tariff contains a unique dedicated vehicle provision which permits the Company to negotiate with organizations individually to determine the charge for services, subject to a maximum rate per mile or per hour.

8.2 Minimum RSVP System Configuration

The level of hardware, software, and personnel support necessary for a specific RSVP System configuration depends primarily on:

1) the number of vehicles in the fleet;
2) the size of the area to be served; and
3) the number of telephone requests expected.

These factors determine the number of meters, radios, and spares; the auxiliary storage; the number of operations consoles and telephone lines required. In addition they strongly influence the complexity of back-up system policies and procedures.

Although fleet size directly determines the number of active RSVP Meters required, it is recommended that a spare meter inventory of approximately

10% be maintained for fleets of up to 200 vehicles. For larger fleets, an inventory level of 7% to 8% should be adequate. Similarly, radio and speedometer sensor replacements should be maintained at approximately a 5% level. In general, it is anticipated that most companys' non-computer related RSVP equipment maintenance philosophies will be to simply replace faulty components (e.g., entire meters or radios) and then ship the malfunctioning units to a central location for repair. Furthermore, it is assumed that all computer-related hardware maintenance will be performed under an appropriate maintenance contract with the computer vendor.

In terms of storage capability, a 75 to 100 vehicle fleet would require two Operations Consoles and a minimum of 24,000 16-bit words of main computer memory. (Assuming the file structures used in the Pittsburgh prototype system, approximately 19,000 words would be necessary for resident RSVP System programs and tables, with the remaining memory used by the RT-11 Operating System). Each additional Operations Console would require approximately 600 words of memory. Furthermore, again assuming file structures as implemented in the prototype, the secondary storage necessary for geographic data files increases exponentially with the number of traffic zones and linearly with the number of streets (i.e., city blocks) in the service area. Pittsburgh data (18,303 street names; 50,483 street links; 456 traffic zones) required 2,306,268 words of disk storage; however, the nature of the hashing algorithm is such that approximately 3.75 million of the available 5 million words are dedicated to data storage.

Back-up computer facilities are required to support real time RSVP shared ride fare calculations; however a specific company's mix of shared and exclusive ride services actually determines whether a completely redundant system is necessary. Regardless of the degree of on-line back-up service, it is necessary to maintain off-line copies of data bases and important system records, and adequate updating policies and procedures must be developed to insure that system operating information can be restored after a hardware or software malfunction.

In the simplest case, zone pricing systems may be developed and if a computer malfunction occurs, fares may be determined manually by looking in a table and then transmitted verbally to vehicles (although such a procedure may cause regulatory problems in some areas). For somewhat more complex, i.e., active systems, the manual look-up of fares could be automated, either via access to another computer system using telephone lines, or through a small stand-alone intelligent terminal system on-site. In this case, since the back-up system would not calculate a fare for each trip, both storage and computation requirements would be substantially reduced. Fares would be communicated either verbally or through the microprocessor interface to the main system. Finally, the most complex systems would probably require either continuous access to a time-sharing service which maintained the appropriate data bases, or complete duplication of on-site hardware and software.

8.3 Initial Operating Results

The use of RSVP System has primarily involved fare calculations for prearranged shared and exclusive ride trips, although it has also been used on a limited basis for on-line, real-time fare calculations. Extensive

off-line fare calculations have permitted fares to be compared with those computed using an electro-mechanical meter; thus the geographic data base has been validated without the risk of a customer being directly confronted with a blatant inconsistency or inaccuracy. Experience thus far has indicated that the basic Pittsburgh area geographic data base is very reliable; however, there are a number of new housing developments with streets that do not currently exist in the file.

RSVP exclusive and shared ride fare calculation formulas have been derived by simulating the electro-mechanical taxi meter; and, as explained previously, the accuracy of the results for exclusive rides depends on the average running speed V of the vehicle. It has been found that the value of V for a short trip in congested downtown business areas is different from that for a longer trip to the suburbs or to the airport, thus an adjustment factor has been added to the formulas for trips longer than 5 miles. The relationship between the exclusive ride fare and the shared ride fare for a party of several persons having the same trip origin and destination and occupying the entire vehicle should be analyzed in greater detail; however, with current operating procedures, all fares for a specific trip are displayed to the dispatcher on the Operations Console as shown in Figure 8.1. The dispatcher then has the responsibility to communicate all options to the customer and to determine what type of service the customer would like to use.

Five prototype RSVP Meters have been installed in five new taxicabs for in-service evaluations. Relatively minor hardware and software problems such as timing problems in transferring data between the PDP-11 and the microprocessor, noise problems in the meter communication circuitry, and simple mechanical/electrical problems of poorly soldered connections or faulty circuit board etching have occurred and been resolved during preliminary operations. Continuation of experimentation will permit rigorous testing and evaluation of the hardware and software, as well as to gain additional insight into user, management, and regulatory perceptions of the System.

8.4 Initial User Reactions

In a brief survey of 27 persons whose employment was transportation related, but who were polled as users of the RSVP System, a number of relevant perceptions emerged that should help guide future surveys and analyses. Forty one percent of the group felt that the System would greatly reduce the fear of unfair operations, while the remaining 59% felt that it would at least moderately reduce such fears. Seventy eight percent felt that the new technology would at least moderatley affect user satisfaction with taxi services, while 15% felt that the effect would be great and 7% felt that there would be no effect. Fifty two percent of the group felt that the fare in advance concept would be easily accepted by the public, 33% felt that it would be moderately easily accepted, and 15% felt that concept would be rejected.

Eleven percent of the group felt that if the fare in advance concept were coupled with pay in advance, tips to drivers would be essentially eliminated; forty one percent felt that tips would be reduced, and 48% felt that tips would remain the same. Fifty six percent of the group felt that shared ride capabilities would attract new ridership, 26% felt that

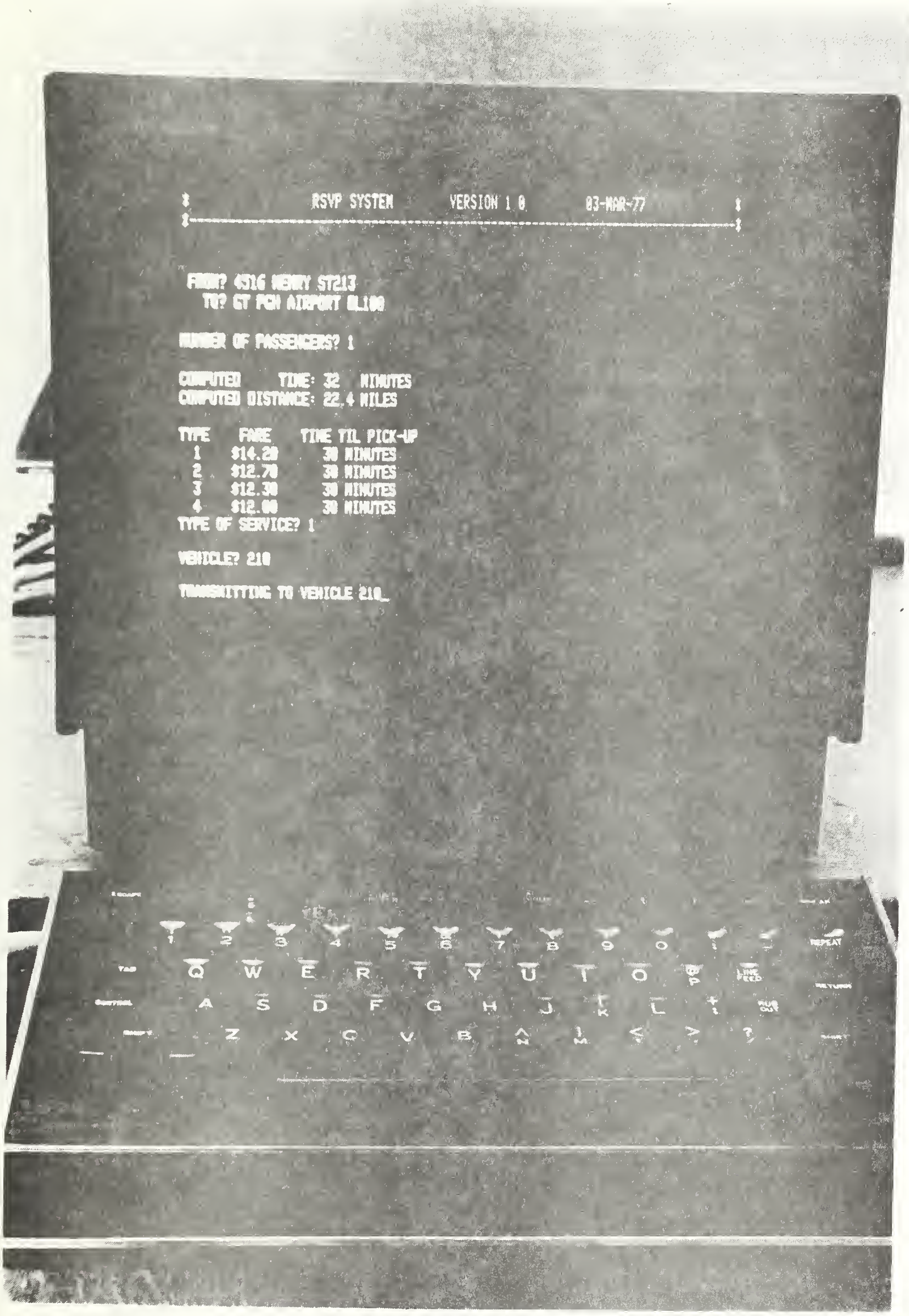


Figure 8.1
OPERATIONS CONSOLE

shared riding would be primarily used by current taxi patrons, and 18% had no opinion on the issue of increased ridership from shared ride services. Seventy eight percent felt that credit card billing would be a necessary adjunct, 19% felt that it would be unnecessary, and 3% had no opinion on the issue. Fifty nine percent felt that automatic printed receipts would be necessary, while 41% felt that they would be unnecessary.

8.5 Market Potential

In order to fully exploit the benefits of shared ride taxi services, it is not sufficient to merely allow their existence. Paratransit services must be implemented and regulated in such a way that operator's profits are not eroded when users are charged fares substantially lower than exclusive ride fares. In general it seems that successful paratransit operations will evolve primarily through the taxi industry. As a response to rapidly escalating costs in the face of uppoer limits to fares, multiple occupancy ride sharing services present a way for taxi companies to increase revenues without incurring corresponding cost increases. Furthermore, as the general public and Federal and State administrators become aware that taxi operators typically provide transportation at costs per mile considerably lower than social service agencies, taxi operators should become eligible for governmental funds for such services. Finally, although bus (transit) operators have expressed interest in paratransit, little has been offered in the way of service. Inter- and intra-urban bus companies provide a service very different from paratransit; thus bus operators cannot gradually evolve into paratransit service utilizing existing fleets and procedures. In contrast, the taxi industry currently provides door-to-door non-scheduled transportation, and is clearly capable of expanding to include shared ride paratransit services.

As a relatively new form of service, paratransit is delineated by two well-defined types of public transportation (bus and exclusive taxi). While both groups claim ownership, important operating statistics have not been aggregated, and reliable national marketing data are difficult to obtain. In the Pittsburgh region, however, recent analyses of general paratransit services and some particular taxi-related paratransit services[7] have shown that a sizable untapped market exists.

Although no proposed levels of service in the experimental operations are entirely new, using a combination of modes to provide multipassenger taxi service raises important questions concerning market development, market aggregation, and potential economies of scale. If these issues can be satisfactorily resolved, the capability to shift dynamically from conventional taxi service to multipassenger service would significantly improve operating efficiency. In particular, a pricing mechanism that would maximize fleet utilization would also reduce congestion and operating costs while allowing the customer to choose a level of service among taxicabs, buses, and other forms of paratransit services.

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[7] Geltner, D., et.al., Taxi Paratransit Services for the Pittsburgh Region, Urban Systems Institute, School of Urban and Public Affairs, Carnegie-Mellon University, Pittsburgh, Pa. 1976.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Current Research Results

The RSVP System represents a significant advance towards understanding some important and heretofore unexplored aspects of hardware and software technology for paratransit operations. The prototype System for Pittsburgh has been designed to illustrate both concept and product potential in a real world experimental environment. Regulatory, technical, operational, and economic factors have influenced System development, and numerous contacts with the Pennsylvania Public Utility Commission have helped to define appropriate procedures for the use of the system's computation, communication, and control techniques in actual taxi operations. The guarantee of a consistent fare for a specific trip (since fares are computed using an algorithm and a well-defined data base), and the inherent real time audit capability of the RSVP System, have provided a rational basis for examining the efficiency and equity issues of exclusive ride and shared ride taxi services.

Analyses of the rationale for and implementation of a variety of institutional and regulatory constraints indicate that such constraints can be overcome with adequate support systems. Thus, RSVP hardware and software are designed to have widespread applicability, though specific system components are tailored to the operating and regulatory environment of Peoples Cab Company in Pittsburgh, Pennsylvania. Certainly, the process of acquiring and validating geographic data is feasible in any major metropolitan area; and file structures are generally applicable to any service territory. Installation of the RSVP Meter in any vehicle at most requires relatively minor modifications of the sensor and communication hardware (to insure a match with the vehicle's transmission and radio).

Perhaps the most important aspect of project implementation derives from the approach used in obtaining regulatory approval for shared taxi service. Peoples Cab Company, in contrast with most other taxi companies in Pennsylvania, chose to file a tariff under its existing Certificate of Public Convenience, rather than to apply for an entirely new certificate. The PUC's acceptance of this approach gives additional strength to the argument that shared ride services (i.e., paratransit services) are and have been clearly in the province of taxi operations. In particular, the tariff approach is extremely significant in Allegheny County, Pennsylvania. Port Authority Transit, the area-wide public mass transit agency, has taken the position that it has the authority to regulate paratransit transportation services if such services are provided in vehicles other than sedan taxicabs. In addition, a number of social service agencies in the County which generally provide transportation to elderly and handicapped persons, are presently involved in the application for replacement equipment under the auspices of section 16 (b) 2 of the Urban Mass Transportation Act. Again, there are jurisdictional questions with far-ranging ramifications that need to be resolved, and the fact that a Certificated taxi company has an approved tariff (as opposed to a temporary certificate for a new service) should be a substantial force to insure that taxi operators are not excluded from the growing paratransit market.

A second significant aspect of development has been the extension of the concept of computer-based point-to-point fare calculations to shared ride services. Several electronic meters with multiple fare capabilities are

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